Reviewed research article

The 1783–1785 A.D. Laki-Grímsvötn eruptions II: Appraisal based on contemporary accounts

Thorvaldur Thordarson[1,2], Guðrún Larsen[2], Sigurður Steinþórsson[2] and Stephen Self[3]

1) Department of Geology and Geophysics, University of Hawaii at Manoa, Honolulu Hawaii

2) Science Institute, University of Iceland, Reykjavík, Iceland; moinui@soest.hawaii.edu, torvth@hi.is

3) Department of Earth Sciences, The Open University, Milton Keynes MK7 6AA, UK

Abstract – *The 1783–1784 Laki eruption along with intermittent explosive eruptions at the subglacial Grímsvötn central volcano, represents a two-year-long volcano-tectonic episode within the Grímsvötn volcanic system, from June 1783 to May 1785. The Laki eruption is the second largest basaltic flood lava eruption in historical times (after the 934–940 A.D. Eldgjá event) and its consequences were disastrous for Iceland. Detailed eyewitness accounts of the Laki-Grímsvötn eruptions exist and are here analysed in order to reconstruct the sequence of events as accurately as possible. This information is catalogued and critical eruption phenomena, such as the timing and nature of seismicity, explosive activity and mechanics of lava flow emplacement is evaluated. The results show that the 1783–1785 activity on the Grímsvötn volcanic system included at least 14 eruption episodes. Ten of these episodes were associated with the eight-month-long Laki eruption and linked to rifting and gradual lengthening of the erupting fissure. Each eruption episode began with an earthquake swarm, leading into a vigorous explosive eruption on a new fissure segment that was followed by sudden increases in outflow of lava. Concurrent explosive eruptions were reported at the Grímsvötn volcano during four of these episodes. The remaining four eruption episodes were confined to the Grímsvötn volcano, which remained active until May 1785. Evaluation of descriptions of flow phenomena in conjunction with new field observations of flow structures indicates that endogenous growth (i.e., insulated transport and inflation) was the characteristic mode of flow emplacement.*

INTRODUCTION

The 1783–1784 A.D. Laki eruption, which took place on a 27 km long volcanic fissure in the Síða highlands of south Iceland (Figure 1), is the second largest basaltic flood lava eruption (after the 934–940 Eldgjá event) in historic time (Thordarson and Self, 1993; Thordarson *et al*., 2001). It represents the main volcanic event of a two-year-long (May 1783-May 1785) volcano-tectonic episode within the Grímsvötn volcanic system, which featured intense earthquake activity and eruptions at the Grímsvötn central volcano in addition to those at the Laki fissures. The consequences of this activity were disastrous for Iceland and the atmospheric and environmental effects caused by the emissions from Laki were felt over large portions of the Northern Hemisphere (Traumüller, 1885; Thoroddsen, 1914; Thorarinsson, 1979; Sigurdsson, 1982; Steinthorsson, 1992; Wood, 1992; Thordarson *et al*., 1993; Fiacco *et al*., 1994; Thordarson, 1995; Grattan and Brayshay, 1995; Grattan, 1998; Thordarson and Self, 2001; 2003).

The events of the Laki-Grímsvötn eruptions are documented in many contemporary Icelandic chronicles (e.g. Einarsson *et al*., 1984; Thordarson, 1990, 1991). This information has been used by volcanologists to infer the course of eruptive events as well as

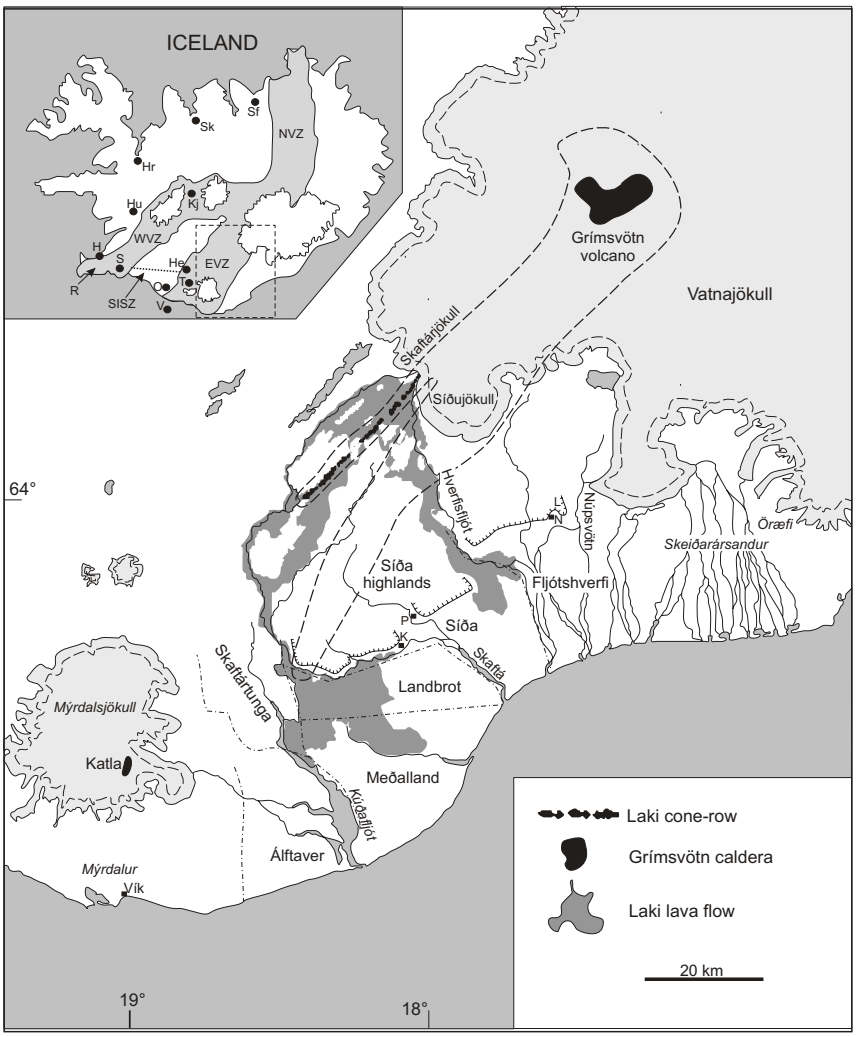

Figure 1. Simplified map of the study area showing the position of the Laki vent system within the Grímsvötn volcanic system (thick broken line) and the location of the Fire districts, the areas most affected by the Laki eruption. District boundaries are shown as broken-dotted lines. Also shown are other districts, the ice caps and outlet glaciers mentioned in the text, along with position of the Grímsvötn and Katla volcanoes. The scarp referred to in the text is shown as hachured lines. The location the farms Kirkjubæjarklaustur (K) and Prestbakki (P) is indicated by filled squares. L and N designate the position of Lómagnúpur Mountain and Núpsstaður farm. Inset shows the location of rift zones in Iceland; box is area of figure and filled circles indicate places elsewhere in Iceland that are mentioned in the text. Abbreviations are as follows: H, Hafnarfjörður; He, Hekla; Hu, Húsafell; Hr, Hrútafjarðará River; Kj, Kjölur; O, Oddi in Rangárvellir; R, Reykjanes; S, Selvogsheiði; Sf, Skjálfandaflót River; Sk, Skagafjörður; T, Tindfjöll and Þórsmörk; V, Vestmannaeyjar; WVZ, Western Volcanic Zone; EVZ, Eastern Volcanic Zone; NVZ, Northern Volcanic Zone; SISZ, South Iceland Seismic Zone. – *Einfaldað yfirlitskort af Vestur Skaftafellssýslu og nágrenni ásamt helstu örnefnum. Innsett kort sýnir staðsetningu rannsóknarsvæðisins.*

to evaluate the mechanics of the Laki eruption (e.g. Thoroddsen, 1879, 1925; Helland, 1886; Thorarinsson, 1967, 1969, 1984; Thordarson and Self, 1993). The accuracy and reliability of these accounts vary greatly, but when evaluated critically and corrected for inconsistencies (see Thordarson, this issue), they are a rich source of information about the course of events. They also provide information about eruption processes that otherwise would be unobtainable.

Here we present a comprehensive compilation and a critical analysis of the information on the course of eruptive events in 1783 to 1785 as revealed in the contemporary chronicles, which are published here for the first time in English. We also present new evaluations of key eruption parameters derived from this analysis. This includes a re-examination of the source, timing and nature of seismic swarms, explosive activity, and lava surges and their inference for number of eruption episodes during this volcanotectonic episode on the Grímsvötn volcanic system. We have also evaluated the characteristic mode of lava flow emplacement using information from the eyewitness accounts in conjunction with new field observations. An extended list of references is included and English translations of the original text used in the reconstruction presented here are given as quotations in the appendix.

GEOGRAPHICAL AND GEOLOGICAL SETTING

GEOGRAPHY

Geographic features and place names are commonly used in the contemporary accounts as reference points for positioning the phenomenon that the authors are describing. Thus to fully comprehend the importance of the descriptions it is useful to have some knowledge of the local geography.

The Laki fissures and lava flow are located in South Central-Iceland in theshire of Western-Skaftafell (Figure 1). A distinct topographical feature in this area is a scarp, an old sea cliff, which trends across the central part of the area from WSW to ENE. Cultivated areas are all located along this scarp or on the Holocene outwash plain to the south and consist of six districts: Álftaver, Meðalland, Skaftártunga, Síða, Landbrot and Fljótshverfi (Figure 1). These districts were most severely affected by the Laki eruption and thus often referred to as the Fire districts. North of the scarp is the Síða highlands, bounded on three sides by the Skaftá and Hverfisfljót rivers. The highlands feature SW-NE trending hyaloclastite ridges separated by low-lying wetlands. A few gorges and smaller valleys trend northward from the main scarp into the Síða highlands, including those of the Skaftá and Hverfisfljót rivers which now are largely filled by the Laki lava (Figure 2). The area around the Laki fissures was boggy before the eruption and the remains of these bogs are preserved along the edges of the lava-filled Úlfarsdalur and Varmárdalur valleys. Northeast of the Síða highlands is the Vatnajökull ice cap where the subglacial Grímsvötn central volcano is located (Figure 1).

GEOLOGY

The Laki cone-row is located within the Grímsvötn volcanic system which consists of the Grímsvötn central volcano and an $\sim$100 km long and $\sim$15 km-wide volcanic fissure swarm (Figure 1). The Grímsvötn volcanic system is tholeiitic in character and is estimated to have erupted between 50–55 km^3 of magma during the Holocene (Jakobsson, 1979). The volume of magma erupted in the ice-free region of the system is 21.5 km^3, of which 15.1 km^3 (or 65%) were extruded by the Laki fissures in 1783–1784. The Grímsvötn volcano has erupted at least 40 times since 1598AD with an average repose period of 10–15 years. The most recent eruptions occurred in 1983, 1996 and 1998 (Thorarinsson, 1974; Jóhannesson, 1984; Guðmundsson *et al.*, 1997; Larsen *et al.*, 1998; Sigmarsson *et al.*, 2000). A noticeable pause in the activity at Grímsvötn volcano occurs from 1785 to 1823, the 38 years following the Laki eruption (Thordarson and Self, 1993).

LAKI FISSURES AND LAVA FLOW

The Laki vent system is 27 km long, extending from Úlfarsdalur Valley in the west towards the tip of Síðujökull glacier in the east (Figure 2). It consists of 10 northeasterly trending en echelon volcanic fissures, which together host more than 140 vents (Figure 3).

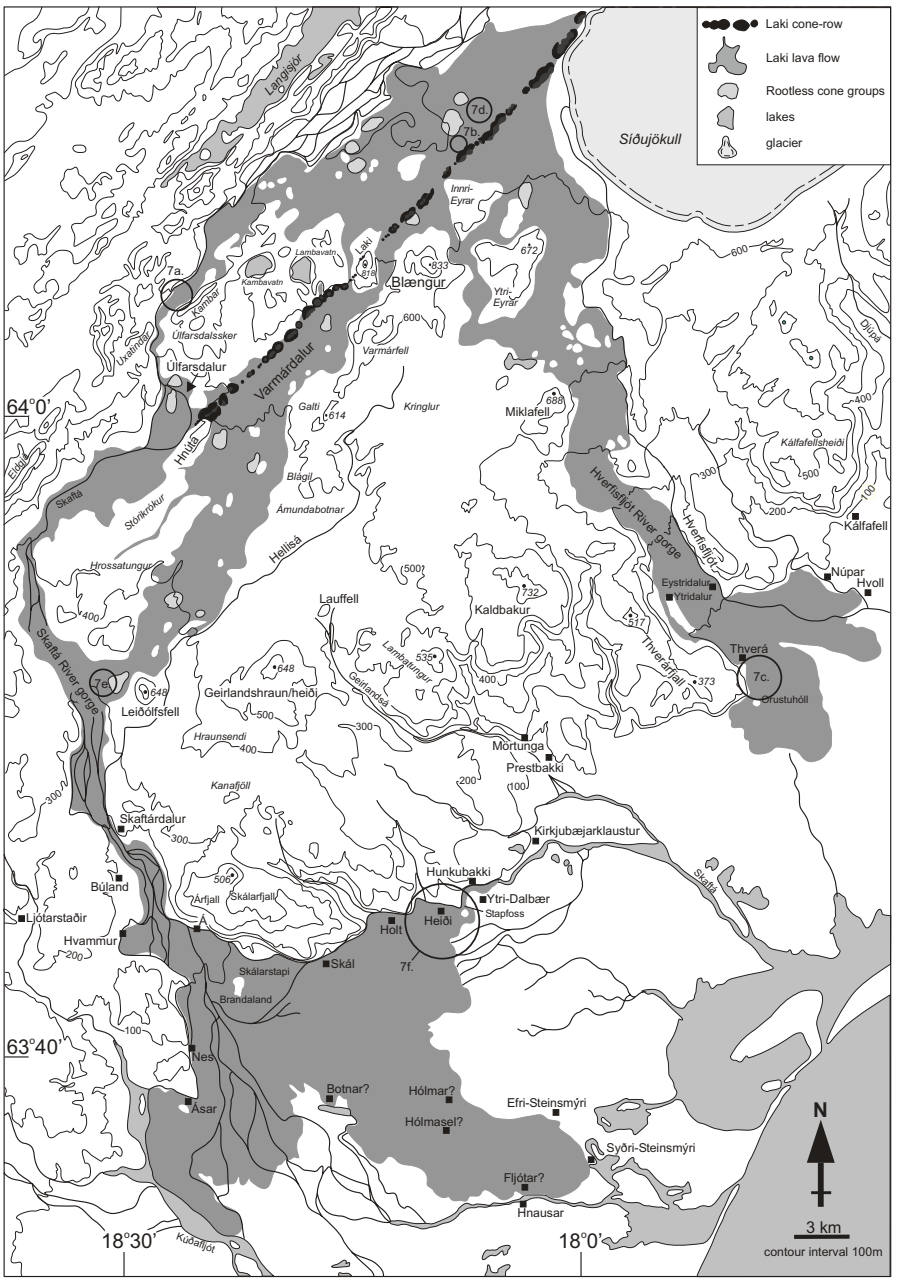

Figure 2. Map of the Fire districts and Síða highlands showing the regional topography, relevant landmarks and place names, along with distribution of vents, lava flows, and rootless cone (pseudocrater) groups. Note that location of farms destroyed by the lava is shown as it was prior to 1783. The pen circles and labels 7a–7f show the locations of the photographs in Figure 7. Modified from Thordarson and Self (1993). – *Örnefnakort af Eldsveitunum og Síðumannaafrétti. Hringir eru dregnir um staði sem sýndir eru á 7. mynd.*

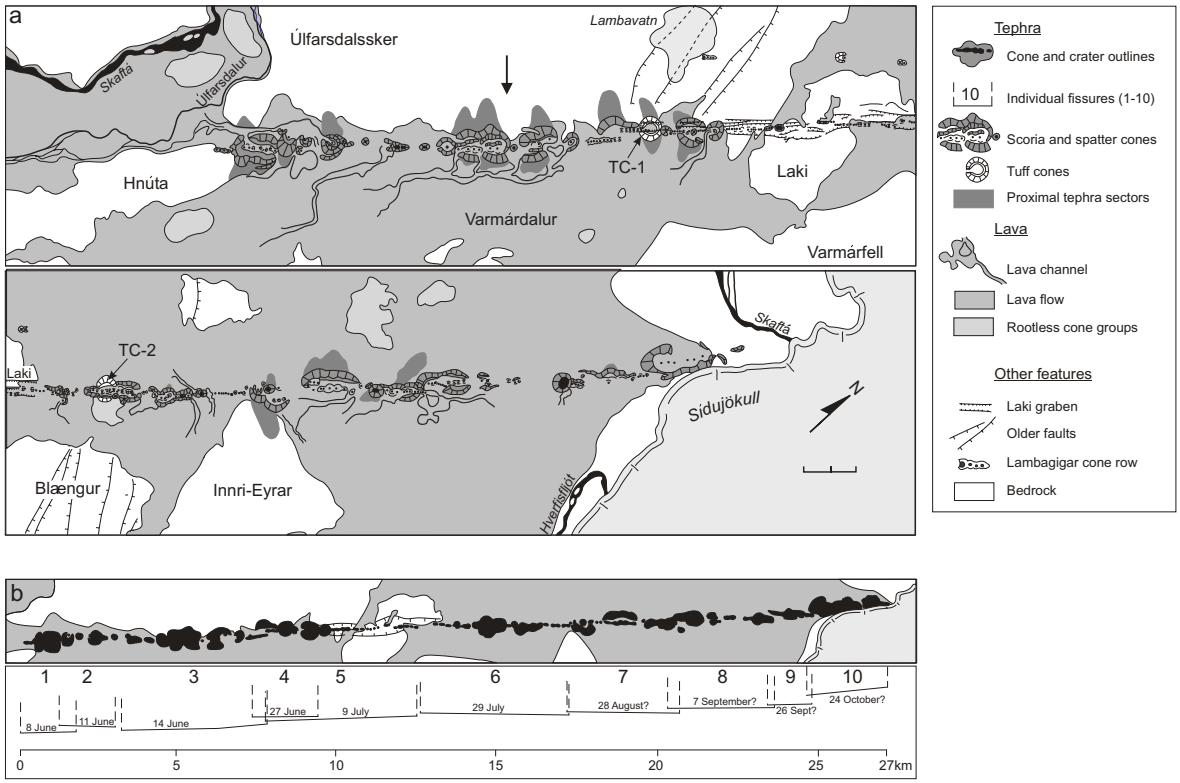

Figure 3. Map of the Laki fissures: demonstrating the main features of the cone-row and surrounding lavas. TC-1 and TC-2 indicate the tuff cones SW and NE of Laki, respectively. Extent of individual fissures, labelled 1 through 10, shown schematically. Cones on fissure 3 (arrow) where first visited and described by Sveinn Pálsson in 1794. – *Lakagígar, gjóskukeilur, gígaraðir og sprungur. Örin bendir á gígana sem Sveinn Pálsson kannaði og lýsti 1794.*

Typically, each fissure is delineated by a row of scoria and spatter cones, although two tuff cones on fissures 4 and 6 interrupt this pattern. Mt. Laki is an older subglacial volcanic edifice, which coincidently subdivides the vent system into two almost equally long segments (Figures 2 and 3). These segments, however, should not be equated with the terms *Útnorðursgjá* and *Landnorðursgjá* used by Steingrímsson in his accounts because he did not know this natural subdivision of the vent system at the time of the eruption. These terms simply refer to on which side of Mt. Kaldbakur the vent activity was visible from the Síða district (Figure 4).

Lava produced on the vents to the southwest of Mt. Laki flowed south over the western part of the Síða highlands in two main lobes; one confined to the Skaftá River gorge and the other to the Varmárdalur and Hellisá river valleys (Figure 2). As the lava emerged from the Skaftá River gorge, it spread out onto the cultivated lowlands of Síða, Landbrot and Meðalland. The vents to the northeast of Mt. Laki issued lava to the south and north away from the fissures. Lava flowing to the south advanced down the Hverfisfljót River gorge, a distance of 25 km, before reaching the lowlands of Síða and Fljótshverfi. Lava flowing to the north spread over the outwash

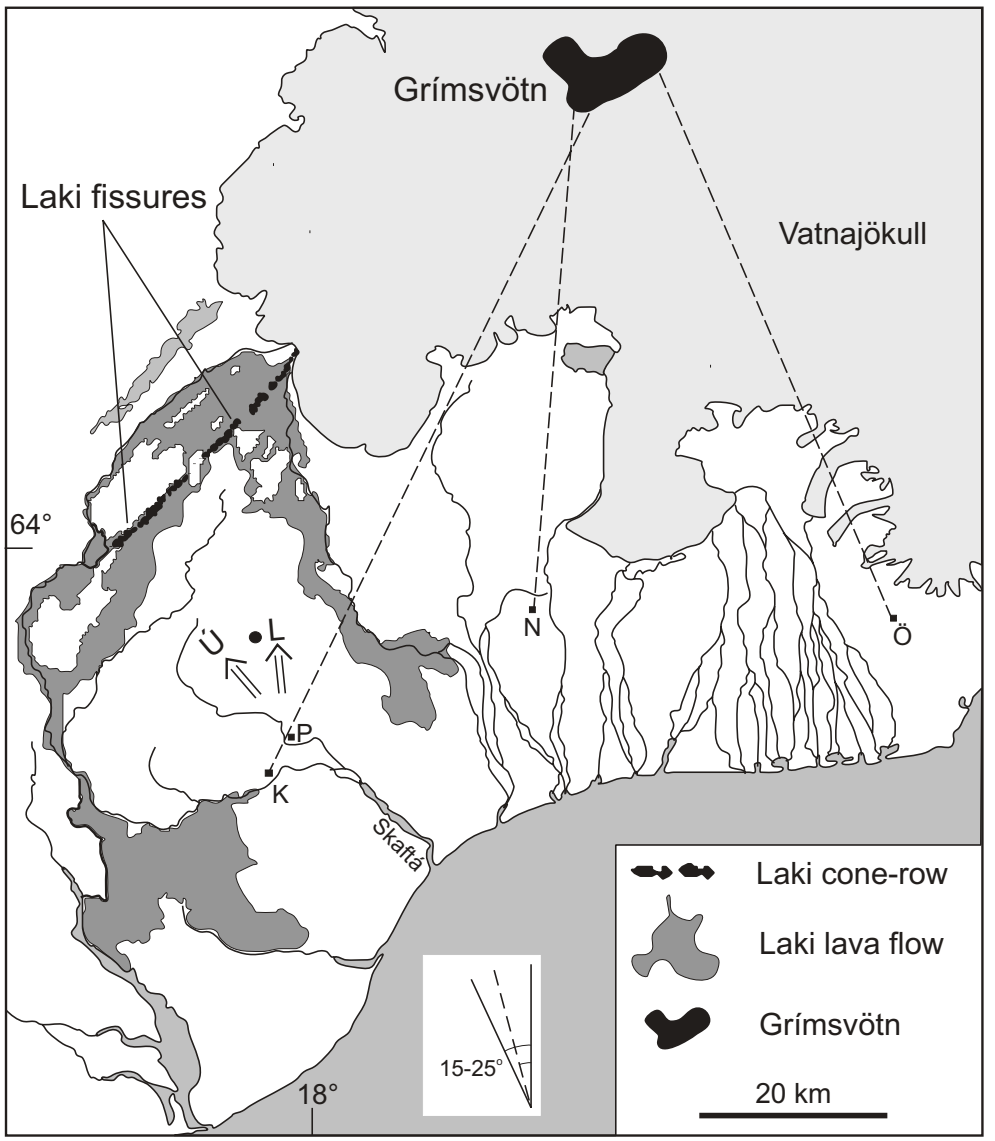

Figure 4. Map showing the relative position of the three eldgjás mentioned by Steingrímsson accounts as it would be when viewed from Prestbakki (P) or Kirkjubæjarklaustur (K). The double arrows point towards Útnorðursgjá (Ú) and Landnorðursgjá (L), respectively and the dot represents the peak of Mt. Kaldbakur. Broken lines show the sightings of the Austur-Landnorðursgjá (Grímsvötn) as described in the contemporary accounts: N, Núpstaður; Ö, Öræfi. The vectors (inset) show the angular offset in sense of directions in the Síða district at the time of the Laki eruption. – *Innbyrðis afstaða eldgjánna þriggja, Útnorðursgjá (Ú), Landnorðursgjá (L) og Austur-Landnorðursgjá (Grímsvötn), sem Jón Steingrímsson vitnar oft til í lýsingum sínum af Skaftáreldum.*

plain of the Skaftá River in front of Skaftárjökull before entering the upper reaches of the Skaftá River gorge. The total magma volume produced by the Laki eruption is $15.1\,km^3 \pm 1\,km^3$, thereof $14.7\,km^3$ was erupted as lava and $0.4\,km^3$ as tephra (Thordarson and Self, 1993).

CONTEMPORARY CHRONICLES

The contemporary chronicles discussed by Thordarson (this issue) provide valuable information about the Laki eruption and are used here to reconstruct the course of events during the 1783–1785 Laki-Grímsvötn eruptions. This information has been catalogued according to the processes it describes and the categories are *seismicity, explosive activity, lava flows, and sense of directions in the Fire districts* (Thordarson, 1990, 1991). Tables A to D in the appendix contain quotations containing information relevant for each of the four categories. Each table is organised such that it relates to the course of events in chronological order.

For the sake of simplicity, the references in the following sections are not to the original accounts, but to the translated quotations tabulated in the appendix. For example, reference (A1) refers to the quotation with index number A1 in Table A. Also note that text enclosed by [ ] are inserted as explanatory notes by the present authors.

GEOGRAPHIC DIRECTIONS AND LOCATION OF ACTIVE VENTS

The geographic features and place names are commonly used in the contemporary accounts as reference points for positioning the phenomena being described. The orientation of certain topographic features affected the inhabitants' perception of geographic directions, and resulting in a 15°–25° counter-clockwise offset of directions in the Síða and Landbrot districts (Figure 4). It is important to consider these offsets to fully comprehend the importance of the descriptions in reconstructing of the course of events (Thordarson and Self, 1988; 1993). Therefore, location of all relevant landmarks referred to in the texts are given on the maps in Figures 1 and 2.

Steingrímsson's references to particular localities give valuable information about sense of direction in the Síða, Landbrot and Fljótshverfi districts (D1–D16) at the time of the Laki eruption. The northernmost boundary of these districts is a 200 m high scarp, trending NE (065–075°) in the Síða and Landbrot districts and E (090°) in the Fljótshverfi district (Figures 1 and 2). The trend of this scarp was the controlling factor on perceived directions and at the time of the eruption, as the scarp was believed to run due east-west along its entire length. This is confirmed by contemporary maps made by Hólm (1771), Stephensen (1785) and Pálsson (1794), where the scarp in the Síða district is shown trending east-west (see Figure 1 in Thordarson, this issue). This results in a counter-clockwise offset of directions given in the Síða and Landbrot districts of the order of 15°–25° (Table 1 and Figure 4). In the Fljótshverfi district, the offset is minimal if any. Steingrímsson lived in the Síða district and most of his directional information is based on local conditions and landmarks in that district. Therefore, the counter-clockwise offset in his descriptions must be accounted for when the directions of reported features are evaluated. This offset in the perception of geographic directions has prompted re-evaluation of some major conclusions reached by earlier studies (e.g. Thorarinsson, 1974, 1984; see also next section).

The offset of geographic directions is consistent in southerly and easterly directions, but is more variable in northerly and westerly directions, with the greatest degree of variation in westerly directions (Table 1). Many of Steingrímsson's observations were made from his home, the farm Prestbakki, but some were also made from the farm Kirkjubæjarklaustur, where the church was located (Figure 2). The relative position of these farms as perceived by the inhabitants at the time differs considerably from their actual geographic relationship. A likely explanation for this discrepancy is the change in the landscape that occurs between these two farms. A large valley, trending NW (320°) cuts into the main scarp between Prestbakki and Kirkjubæjarklaustur. On the old maps this valley is shown trending due north and Prestbakki is shown NE to ENE (055–080°) from Kirkjubæjar-

klaustur, where the true direction is N15°E (Figure 2 and Figure in Thordarson this issue). Because of the mistaken direction of the valley between the farms, references to the geographic west in the vicinity of Prestbakki are slightly north of west (or 280–300°). This effect can be seen in some of Steingrímsson's descriptions of tephra fall that he reported to have been dispersed by westerly wind (D10). On the other hand, Kirkjubæjarklaustur is situated right under the scarp and at that location geographic west was inferred to be parallel to the scarp (245–255°) and therefore resulting in a southward displacement of the reported westerly directions at this location.

Table 1. Direction (in degrees) of geographic directions as they were sensed in Síða district at the time of the Laki eruption and their offset compared to true geographic directions. – *Frávik átta á Síðunni á 18. öld.*

Cardinal directions	True position[1] *rétt stefna*	Offset[2] *frávik*
Northwest	320° to 325°	+5° to +10°
North	—	—
Northeast	345° to 360°	- 45° to -60°
East northeast	20° to 30°	-37.5° to -47.5°
East	65° to 70°	-20° to -25°
Southeast	120° to 135°	0° to -15°
South	—	—
South-southwest	181°	-21.5°
Southwest	215° to 225°	0° to -10°
West-southwest	245° to 255°	-2.5° to +7.5°
West	250° to 300°	-20° to +30°

1) Geographic directions in degrees (east of north) as estimated from position of landmarks used as a point of reference by Steingrímsson in his accounts.
2) Shows deviation of the values in column 2 from the true geographic directions. Clockwise offset is indicated by plus sign, counter-clockwise by minus sign.

A considerable offset is also in reported northwest and northeast directions, which after correction become; NW = 325°, NE = 345–360° and ENE = 20–30° (Table 1). It is vital to keep this discrepancy in mind when locating the active vents during the Laki eruption using the contemporary accounts. In the following compilation of the eruption, geographic directions are given as stated in the contemporary accounts (i.e., not corrected), unless otherwise noted. Degrees, when given, refer to the actual geographic directions.

LOCATION OF ERUPTION VENTS

Reverend Steingrímsson (1783; 1788) identifies three distinct eldgjás[1] in his accounts of the Laki eruption. These eldgjás indicate the sites where he saw fire or ash columns rising from the active vents from his home, the farm Prestbakki. Two of these gjá's clearly refer to segments of the Laki vent system, whereas the third gjá indicates vents that were situated a good distance to the east of the Laki fissures (e.g. Thordarson and Self, 1988; 1993).

During the first days of the Laki eruption, the fires were seen rising above the moors to the west of Mt. Kaldbakur, in the direction of the Mörtunga farm (320–325°) when viewed from Steingrímsson's home, Prestbakki (Figure 2). These sightings indicate that the fire fountains at the very beginning of the eruption emerged from the southwestern most vents on the Laki fissures near the Hnúta Mountain. As demonstrated by Thordarson (this issue), these vents are situated right in front of the now lava-filled Úlfarsdalur valley, as is stated in Steingrímsson's accounts (B26). He refers to these vents as either *Útnorðursgjá* (the northwest vents) or *Vesturgjá* (the west vents), terms that he later applied to all vent activity visible to the west of Mt. Kaldbakur. On 29 July, eruption columns were seen rising for the first time above the eastern shoulder of Mt. Kaldbakur, in the direction of Mt. Blængur (Figure 2). The line of sight to these vents (i.e., fissure 6 on Figure 3) is 10° to the west of north but not to the northeast as indicated in the original accounts. In his descriptions Steingrímsson refers to this and other vent activity that revealed itself to the

[1]Eldgjá is a term that is often used in old Icelandic literature to describe erupting vents or sites. Literal translation of the term is "the fissure of fire" and is clearly derived from the most common experience Icelanders have had with volcanic activity, a fiery display of fountains emerging from a linear vent system or a fissure. Here, Steingrímsson uses the term more loosely or simply to indicate erupting vents.

east of Mt. Kaldbakur as either *Landnorðursgjá* (the northeast vents) or *Austurgjá* (the east vents).

The fires at the third eldgjá were seen at least 10 times from July 1783 to May 1785 (Steingrímsson, 1788). These fires were situated east-northeast of Kirkjubæjarklaustur according to observers and referred to as *Austur-Landnorðursgjá* (the east northeast vents). The actual location of this site has been debated in the past, because no historical eruption sites are known due east-northeast of Prestbakki or Kirkjubæjarklaustur (Thoroddsen, 1925; Thorarinsson, 1974; Thordarson and Self, 1988). However, the following quotations taken from Steingrímsson's descriptions give a clear indication on the location of this eldgjá:

26 September 1783: "Another additional fire and steam column, which had been seen before that summer, far east-northeast of the Síða district, due north of Lómagnúpur mountain, but north-northwest of Öræfi district, as it was oriented by me and 8 others."

January 1784: "Fires were still seen at the East-northeast fissure. From Klaustur [i.e., Kirkjubæjarklaustur], these fires were seen behind the northern end of Þverárfjall mountain. The inhabitants of Öræfi district had a better view of these fires due to their location."

Firstly, these descriptions show that this *eldgjá* (i.e., eruption site) was separated from the other two by a considerable distance to the east. Secondly, despite the fact that Steingrímsson says the fires were east-northeast of Kirkjubæjarklaustur, his directional information indicates otherwise. The fires were seen behind the northern end of Þverárfjall, showing that they were actually located to the north-northeast (20–30°) of Kirkjubæjarklaustur (Figure 4). The only way these fires could be observed from the vicinity of Lómagnúpur Mountain was through the valley of the River Núpsvötn, which is located along the eastern side of the mountain. This valley trends 3° east of north. The third orientation given by Steingrímsson is from the Öræfi district east of Skeiðarársandur, where the fires were seen to the north-northwest. When these three cardinal references are plotted, it is clear that the *Austur-Landnorðursgjá* eruption site was at the Grímsvötn volcano (Figure 4).

COURSE OF EVENTS AS REVEALED BY THE CONTEMPORARY ACCOUNTS

THE PRECURSORS OF THE ERUPTION

A farmer, Jón Eiríksson at Ljótarstaðir in the Skaftártunga district observed the first sign of activity in the area when he felt weak tremors in mid-May 1783. These tremors largely went unnoticed until 29 May when they increased to such an extent that the inhabitants in Skaftártunga district evacuated their homes and slept outside in tents for their own safety. On 1 June strong earthquakes were felt over an area extending from Mýrdalur in the west to Öræfi in the east, to a distance of about 75 km from the Laki fissures. The intensity and duration of these earthquakes steadily increased through the first week of June or until the onset of the eruption on 8 June (A1–3).

Signs indicating volcanic activity were seen in the mountains or in the glaciers above the Fire districts in the spring 1783 before the onset of the Laki eruption. The crew of a brig claimed that they saw fires somewhere above the Fire districts, as well as southwest of the Reykjanes peninsula, as they were passing the southern coast of Iceland on their way to Hafnarfjörður in SW-Iceland (Figure 1, inset). It is not known whether this brig was the Boesand, which arrived at the beginning of May or the Torsken, which arrived around 20 May. It was also reported that the inhabitants of the Fire districts often saw a bluish smoke above the ground, which they related to volcanic activity (B1). The location of the above-mentioned activity is unknown, but may have been within the Vatnajökull ice cap because the inhabitants of the Fire districts did not specify the location of the site.

In summary: The Laki eruption was preceded by 3–4 weeks of seismic activity. It began with weak earthquakes in mid-May 1783 that increased in intensity and frequency until the beginning of the eruption on 8 June. If the observation by the brig's crew is correct, this precursory phase may have resulted in a short-lived eruption sometime in May 1783.

FIRST 45 DAYS OF THE ERUPTION

In clear and calm weather on Whitsunday, 8 June 1783, at about 9 a.m., people in the Fire districts

saw a black volcanic cloud rise up north of the highest mountains bordering the Síða district. It spread out rapidly towards the south with tephra fall in Síða and the western part of Fljótshverfi (Figure 5a), such that it became dark indoors at midday. Black ash-like dust and "hairs" (i.e., Pele's hair) covered the ground. Rainfall later that day contained so much volcanic dust that it looked like black ink (B3–11). No tephra fall occurred in the adjacent Skaftártunga district (B7). Later that day columns of fire were seen both from Síða and Skaftártunga. According to Reverend Einar Björnsson during his visit at Prestbakki, three fires were seen northwest of the farm Mörtunga (B8). Steingrímsson describes the same fires as numerous columns of fire (B3). Jón Eiríksson saw one column of fire on 8 June (B7). Tephra fall eased in the afternoon on 8 June, which coincided with the arrival of southerly sea breeze (B4). The following day the plume was clearly visible from the Síða district and still rising. A rainfall that evening was reported to be from the volcanic cloud (B12).

The weather was cloudy on 10 June and acrid ash laden rain containing Pele's hair poured down most of the day. The rain was accompanied by a sulfurous stench and was so polluted that it afflicted the people with dizziness and smarting in their eyes and skin. The raindrops burned holes through leaves and produced spots on the skin of newly shorn sheep (B13–15). On 11 June there was a strong wind from the east with snowfall and drift (B17). Tephra-fall was only reported from the moors above Skaftártunga (B19, Figure 5a). On this day Jón Eiríksson at Ljótarstaðir in Skaftártunga noticed two new eruption sites to the northeast of the first one (B18). Between 11 and 14 June, Árni Thorarinsson saw three separate eruption columns from his home, Oddi in Rangárvellir, over 100 km to the west of the eruption site (B20). Earthquakes recommenced in the early hours of 9 June and increased continuously until 11 June, which was the last day of the continuous earthquakes (A4–7).

On 9 June, the flow of water in the Skaftá River began to dwindle considerably and its channel dried up on 10 or 11 June, apart from for the run off from local tributaries (C3–7). A friend, who lived at the farm Skál in the Síða district, sent a letter to Sveinn Pálsson. The letter describes a trip undertaken on 11 June by him and a few other men that went woodcutting in the Síða highlands along the eastern side of the Skaftá River gorge. The riverbed had dried up so they let the logs fall into the gorge. At the same time, they noticed a huge steam cloud rise up from the northern part of the gorge. Later that day they observed a glowing lava stream, filling the gorge and advancing rapidly (the position of this lava front is shown on Figure 5a). While they collected their belongings the lava flowed over and burned all of the logs they had cut down (C7).

On 12 June the first of five lava surges emerged from the gorge onto the farmlands located on the glacio-fluvial sandur plain in front of it (C8–12). At the end of the day, the flow front had reached the fields of the farm Á, about 3 km south of the mouth of the gorge (C9; Figure 5a). On 14 June the front was reported to be 20 fathoms (about 35 m) away from the graveyard at the farm Skál (C13), some 30 km south of the first fissure to open.

On 13 June, the wind was from the southwest and the eruption column rose high enough (i.e., »2 km) that it could be seen from Selvogsheiði in southwestern Iceland, 300 km away (B23–24). On this day an exploratory party climbed Mt. Kaldbakur to the north of the Síða district to get a good view over the eruption site. Steingrímsson notes that these men saw 20 fire columns (fountains) in Úlfarsdalur Valley and 7 others in the hillock further to east (i.e., Úlfarsdalssker) (B25–26). The only lava stream seen by these farmers was the one in the Skaftá River gorge. Earthquakes recommenced on 13 June (A8–11) and on 14 June, in calm weather and a light southerly breeze, a substantial tephra-fall was reported in the Síða district (Figure 5b). This tephra fall contained such an abundance of Pele's hair that it rolled up into elongated bundles blown around by the wind. Steingrímsson clearly states that this tephra-fall contained much more of the *hairy material* than previous ones. Acid and ash-laden heavy rainfall, as previously described on June 10$^{\mathrm{th}}$, occurred that night despite the southerly wind (B27–29). The night before the 15$^{\mathrm{th}}$ a second lava surge came out of the Skaftá River gorge resulting in further advance of the lava front onto to the plains in front of

the Síða highlands (C13–14, Figure 5b). Activity at the fissures continued with vigour (B30–32). On the 17$^{\text{th}}$ of June the wind was from the north and it was on this day that Steingrímsson saw from his home a reddish blaze and sparks of fire (i.e., glowing magma blobs) rising above Geirlandsheiði (C15). This activity has been shown to have resulted from rootless vent eruptions in Laki lava in the vicinity of Mt. Leiðólfsfell, demonstrating that by this time the lava in the Varmárdalur valley had begun its advance down the Hellisá river channel (Figure 5b, Thordarson *et al.*, 1998).

On 18 June, the third lava surge emerged from the Skaftá River gorge (C16–17) and was accompanied by earthquakes (A12–13). This lava surge was enormous and the lava advanced rapidly in two branches. One branch progressed to the east following the channel of the Skaftá River, while the other advanced rapidly down the channel of the river Melakvísl reaching the Steinsmýri farms on 22 June, travelling 15-16 km in about 5 days (C18–20, C22–23; Figure 5b). On 20 June, the farmers took another trip to the mountains north of the Síða district to observe how the eruption was proceeding. Three lava streams were seen emerging southwards from the vents into the Varmárdalur Valley. As these lava streams merged they advanced southwards over the boggy pasture and the fluvial plain of the Hellisá River (C21). The flow continued down the riverbed of Hellisá until it joined the earlier lava flow in the Skaftá River gorge just west of Leiðólfsfell (Figure 2). Sources from Skaftártunga indicate that lava in the Hellisá River channel was flowing into the gorge by 24 June (C25, Figure 5c).

On 21 June, the wind was blowing from the east along with sleet and snow. A considerable fall of sandy tephra was reported from Síða while greyish coloured sand was observed on thin boards and white paper in Skagafjörður, Northern Iceland (B34–35; Figure 1, inset). Easterly winds continued through 22–25 June (B36–40). Earthquakes were felt again on 23–26 June (A14) and at the same time the lava advanced at a steady rate from the gorge (C24). Explosive activity increased between 23–25 June, but the plume was directed westwards by the wind and may have caused tephra to fall north of Mýrdalsjökull (B39–40, Figure 5c).

On 27 and 28 June, with a strong westerly wind, a considerable tephra-fall occurred in the eastern part of the Fire districts (i.e., in Síða and Fljótshverfi districts; B41–43, Figure 5c). Steingrímsson's description of the tephra fall on the 27$^{\text{th}}$ is as follows: "We here in the Síða district saw a huge black sandy cloud rise up from Vesturgjá, which twisted and spun over the mountains forming bolsters [i.e., cumulus-shape plume]. This cloud dispersed sandy ash containing some pumice-like lapilli scoria over Fljótshverfi and the eastern part of Síða and produced by far the most voluminous tephra-fall in these districts." (B41)

This tephra-fall continued through the 28$^{\text{th}}$, forcing farmers in Fljótshverfi away from their homes and to seek refuge in the settlements west of the Fire districts (B43). The wind was easterly on 29 June and the fourth lava surge emerged from the Skaftá River gorge that day (C26). From that time until 12 July, lava flowed continuously out from the gorge, although at pulsating rates, further enlarging the flow field (C27, Figure 5c).

A considerable amount of tephra fell in Síða on 9 and 10 July, but it did not reach the Meðalland district (Figure 5, B48–50). Increased activity was noted on 13 July, with thunder, lightning and earthquakes for the next four days. The flow rate of the lava increased and the last big lava surge emerged from the gorge on 13 or 14 July and the subsequent advance of the lava fronts completed the construction of the western flow field in front of the Síða scarp (C28–29, Figure 5d). However, lava was seen flowing in the gorge for the rest of the summer (C32, C36). The intensity of the eruption appears to have increased between 18 and 20 July, such that livestock gathered in groups because of seismic activity and earthquakes were reported on the 20$^{\text{th}}$ (A18–19, B52–53, C30–31). On 18 July, ash fell in the Síða and Fljótshverfi districts and Steingrímsson describes it as follows: "When these above described phenomena had been going on the whole night and a large part of the day, a sandy and muddy ash was dispersed over the ground here so it blackened. This tephra-fall came from east-northeast and differed from previous ones in colour and touch. It came from another eldgjá [i.e., Austur-Landnorð-

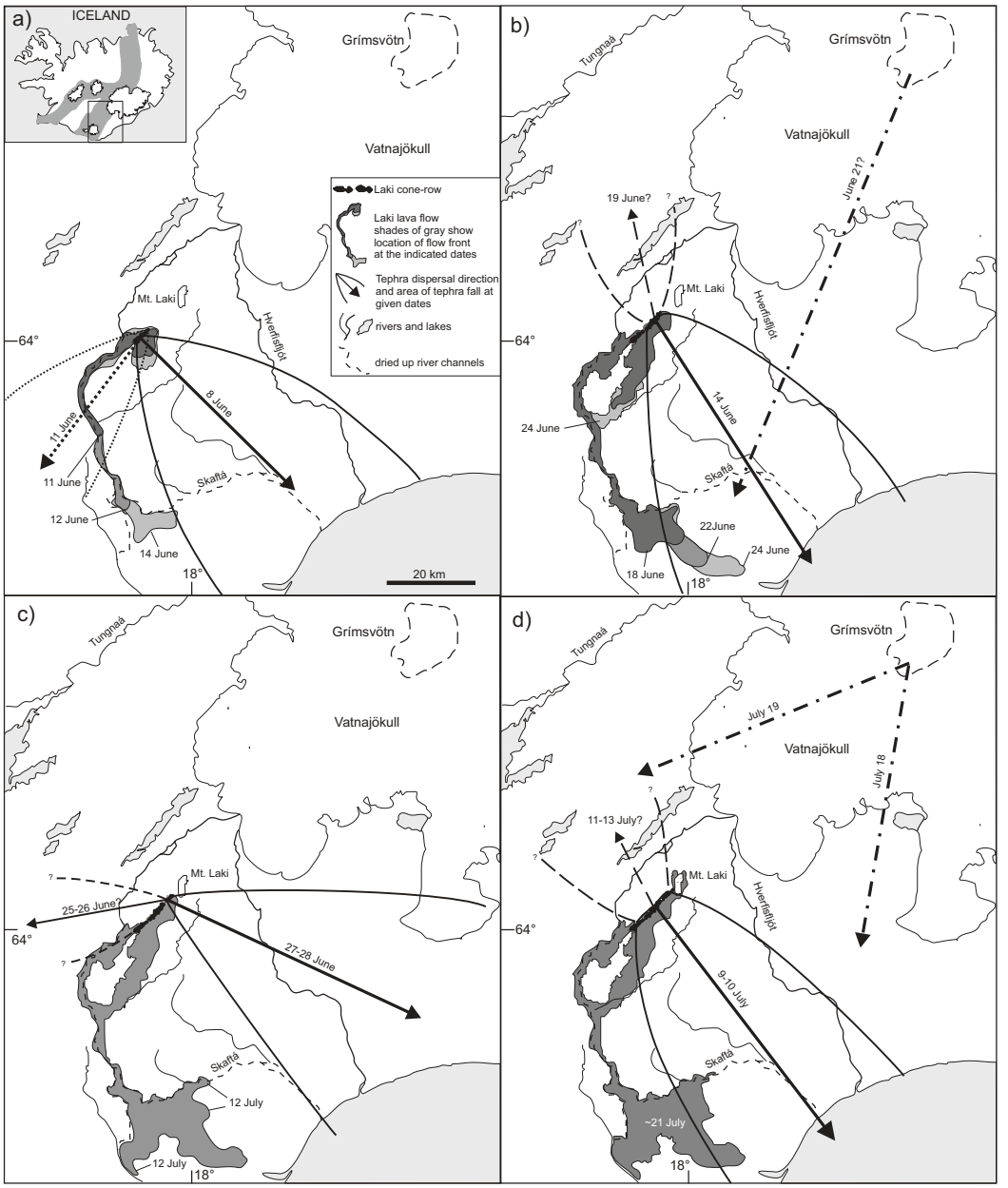

Figure 5. a-g) Origin, timing, and dispersal of reported tephra falls in summer and fall 1783. The position of the lava flow front as indicated in the contemporary descriptions at the given dates is also shown, depicting the approximate growth of the lava flow field with time. – *Uppruni, tímasetning og útbreiðsla gjóskufalls og hrauns frá Lakagígum og Grímsvötnum sumarið og haustið 1783.*

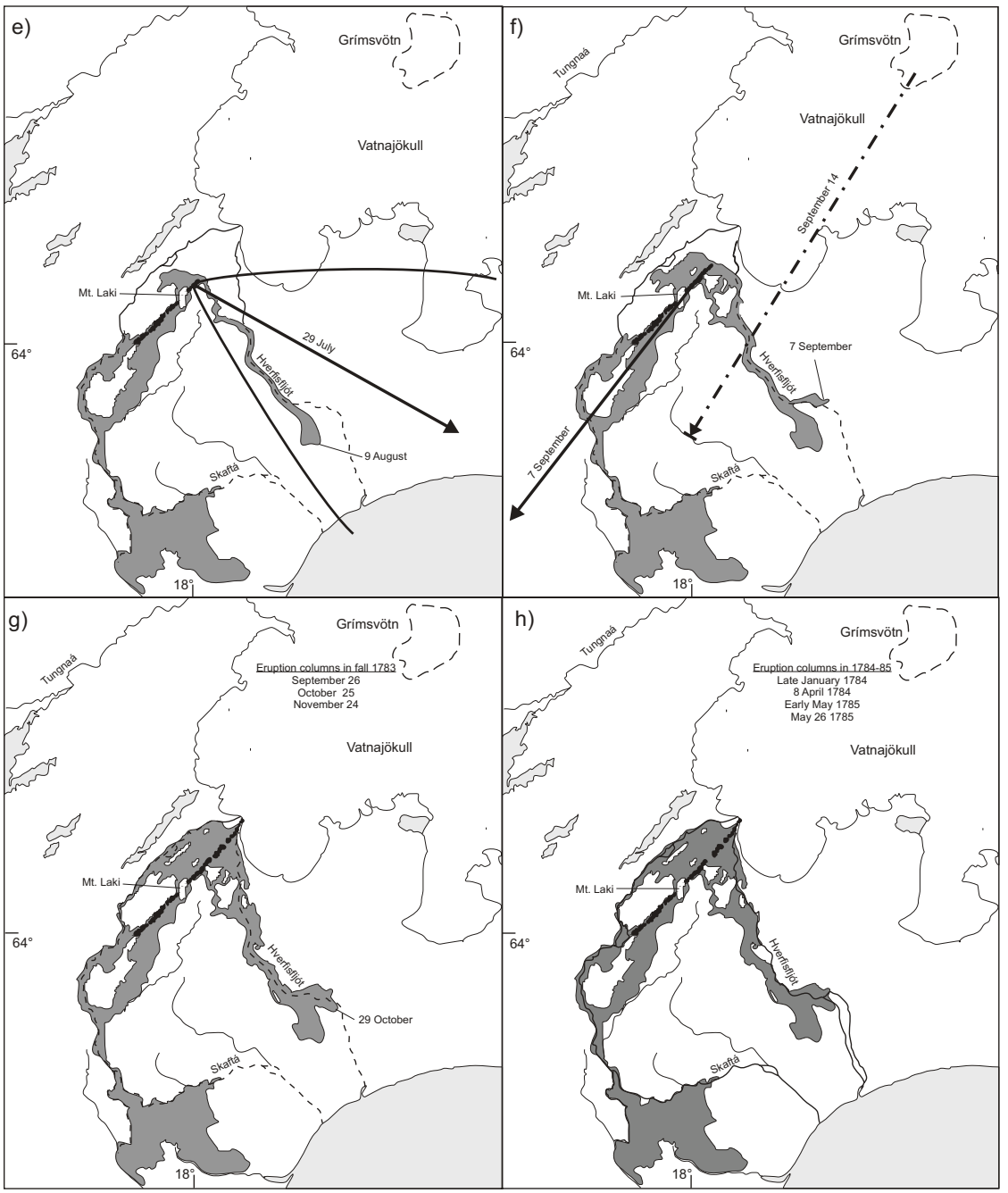

Figure 5. cont. h) Dates when eruption columns or other activity was noticed at the Grímsvötn volcano in 1784 and 1785. – *h) Tímasetning þegar gosmökkur sást rísa upp frá Grímsvötnum.*

ursgjá] as later became evident." (B52) [This tephra fall originated at Grímsvötn volcano, see also Figure 5d].

On 19 and 20 July, this ash cloud was directed towards the west by easterly winds, but to the northwest on the 21st (B54–56). From that day: "no loud rumbling sounds were heard from the Vesturgjá, despite the fact that fires were seen and lava continued to flow from it into September." (B56)

Fires were seen at the fissure to the end of July and an intense fire-coloured glow was seen in the sky on 24 and 25 July (B58, B60). Fine ash, described to look like finely ground tobacco, fell at the Kjölur mountain-route some time before 24 June, about 250 km north-northwest of the Laki fissures (B59; Figure 1, inset). On the 28th rain containing ash fell in Síða district and was accompanied by a bad stench (B61).

In summary: The chronicles report seven occurrences of tephra fall in the Fire district during the first 45 days of the eruption (Figure 5a-d). Five of these tephra falls can be traced back to the Laki fissures, whereas two (i.e., 21 June and 18–21 July) clearly originated from a more easterly source, namely at the Austur-Landnorðursgjá (= Grímsvötn volcano). The chronicles also show that five of the tephra falls from the Laki fissures were preceded by an increase in earthquake activity and that each was followed by a major lava surge emerging from the Skaftá River gorge three to five days later (Table 2). The end of this period also associated with marked change in the eruption, as the focus of activity was shifted to sites the northeast of Mt. Laki (see below and Figure 3).

COURSE OF EVENTS IN LATE SUMMER AND FALL 1783

On 29 July, rumbles and a boiling sound were first heard north of Mt. Blængur, accompanied by tremors of similar intensity to those generated by the activity on Vesturgjá. Shortly thereafter, a "huge and dreadful" volcanic cloud emerged from this site, dispersing sandy ash and pumice-like scoria over Fljótshverfi and the eastern part of Síða (B62, Figure 5e). Earthquakes continued and were felt intermittently throughout August (A20–21). The water in the Hverfisfljót River began to warm up on 3 August when a steam cloud was seen advancing down its gorge. The river dried up the following day. The first lava surge emerged from the gorge on 7 August and two days later the lava had advanced 4 km beyond the hill Orustuhóll (C37–40, Figure 5e).

Intense rumbling and cracking was heard from the new fissure between 30 July and 7 August and a continuous boiling sound was heard until 23 August (B63, B66, B68–70). Southwesterly winds kept the eruption column away from the Fire districts for the first two weeks of August, except for 6 August when fine-grained tephra was dispersed over Fljótshverfi (B67). Showers containing ash fell in the Síða district between 17 and 23 August (B72). Some time between June and August the Laki eruption column was seen from the farm Húsafell in western Iceland rising above the eastern part of the Kaldidalur Valley (B71), indicating column heights in excess of 9 km (Thordarson and Self, 2003). The lava emerged at a steady rate from the gorge until 14 August, but then the outflow of lava dwindled considerably and remained so through August (C42).

Earthquakes started again on 23 August and continued to the end of the month (A21). On 1 September a second lava surge emerged from the Hverfisfljót River gorge and in the following days a branch of the lava advanced rapidly to the east towards the farm Núpar (Figure 5f). The flow of lava was so intense on 7 September, when Steingrímsson crossed the Hverfisfljót sandur plain on that day all the rivers and streams were dry (C43–44). In the Fire districts the first week of September was characterised by sandy rain, mist, thunder and lightning (B76).

Ash-fall was reported in Vestmannaeyjar on the 7th, lasting for 2–3 hours (B77, Figures 1 and 5f). The third lava surge emerged on 10 September and the lava flowed in between earlier lava (C45). September 14 came with an easterly wind and heavy ash-fall which only reached as far west as the Geirlandsá River (B78, Figure 5f). From this day until the 26th an intermission occurred in the flow of lava from the Hverfisfljót River gorge and the flow of water resumed (C46). According to Steingrímsson, the Skaftá and Hverfisfljót rivers reappeared in their gorges at this time. The glow of fire was seen at night above the mountains and

Table 2. Timing of earthquakes, explosive activity and lava surges during the Laki-Grímsvötn eruptions in 1783–1785. – *Atburðarás og einstakar goshrinur Skaftárelda og Grímsvatna 1783–1785.*

Earthquakes *jarðskjálftar*	Tephra Fall *öskufall*	Lava surges *aukið hraunrennsli*	Eruption episodes *goshrinur*
19 May–8 June	8–9 June	12 June	I
9–11 June	10–11 June	14 June	II
13–19 June	14 June	18–20 June	III
	21 June[3]		?
23–26 June			
30 June	25–28 June	29 June	IV
14 July	9-10 July	14 July	
17–20 July	18–19 July[3]	18 July?[2]	V
29 July?			
1–3 August	29–30 July	7 August	VI
23–31 August		2 Sept.	VII
	7 Sept.		
	14 Sept. [3]	10 Sept.	VIII
26 Sept.		26 Sept. [4]	IX
24–? Oct.	25 Oct. [3]	25–29 Oct.	X
2 Nov.			?
24 Nov.	24 Nov. [3]		XI
	Jan. 1784[3]		XII
Feb. 1784[1]			
	8 April 1784[3]		XIII
14–25 Aug. 1784[1]			
	4–26 May, 1785[3]		XIV

1) These earthquakes were not directly linked to the Laki eruption or the volcano-tectonic episode at the Grímsvötn volcanic system. See text for further discussion.

2) Steingrímsson's description imply vigorous activity at the fissures on this day (i.e., B30), but does not directly indicate increase in lava production and no lava surge was observed from the Skaftá River gorge.

3) Fires seen at or tephra fall from Austur-Landnorðursgjá (i.e., Grímsvötn volcano).

4) This lava surge never reached the lowlands, but increased lava production is indicated by cessation of flow in both Hverfisfljót and Skaftá rivers.

from the farm Prestbakki it was observed to be most intense in the lows between Kaldbakur and Lambatungur in the northwest and Kaldbakur and Vothamrar in northeast (B79).

Strong earthquakes were felt again on 26 September (A22). The emission of lava from the fissures increased to such a degree that most rivers ceased flowing, including the Skaftá and Hverfisfljót rivers (C47). This was accompanied by, "An additional column of fire and steam, which had been seen few times before [i.e., 18 July] far east-northeast from Síða, due north of Lómagnúpur, but northwest from Öræfi district." (B80, Figure 5g).

This activity continued at a diminishing rate until 24 October when intense earthquakes were felt in the Fire districts and an acrid stench was emitted from the east-northeast (A23). On 25 October, a huge column of fire rose from the Austur-Landnorðursgjá and rain containing sandy ash fell in the Síða district (B81–82). The same day an intensive lava surge emerged from the Hverfisfljót River gorge and in the following five days the lava filled in the gap in between two earlier flows (C48, Figure 5g). This was the last lava surge

to come out of the gorge. Throughout November, lava continued to issue from the fissures but the new flows were confined to the highlands (C49). Rainfall, containing ash and sand occurred frequently in late October to November (B83). On 24 November, a strong earthquake was felt in the Fire districts (A25), which was followed by increased activity at Austur-Landnorðursgjá, such that the fire column was seen to rise above Mt. Kaldbakur (Figure 5g). In the beginning of December the fire glow above the Laki fissures, which so far had been seen every night, began to diminish (B83). However, lava was still emerging from the fissures and the bluish haze continued to hover over the Fire districts (C49).

In summary: Three tephra falls are described in the chronicles for this period of the eruption (Figure 5e and f). Two of these tephra falls (29 August and 7 September) are traced back to the Laki fissures and one (i.e., 14 September) is inferred to have originated at the Austur-Landnorðursgjá. Also, distinctive explosive eruptions occurred at the Austur- Landnorðursgjá on 26 September, 25 October and 24 November (Figure 5g). Similar to the occurrences early on in the eruption, the explosive activity is closely associated with occurrences of earthquake swarms and lava surges. This time the lava surges emerged from Hverfisfljót River gorge because of the northeast shift in the location of the most active vents (Figures 2 and 3).

THE FINAL SCENARIO

A sulfuric stench filled the air in the Fire districts frequently throughout 1784, especially when the wind was blowing off the vent areas. This was also commonly noted in calm weather and on rainy days (B86). The residents of the farm Skaftárdalur in Skaftártunga saw fires at the Laki fissures until 14 January 1784. According to Steingrímsson, no activity was observed on the fissures after 7 February 1784 (C50).

The Austur-Landnorðursgjá continued to erupt through the winter of 1784 (B86–87; Figure 5h). Flash flooding (jökulhlaup) occurred in the Núpsvötn (Súla) River on 8 April and at the same time a huge black volcanic cloud rose from Austur-Landnorðursgjá. Steingrímsson reports that ash from this eruption site fell twice in the Fire districts, but most of the time the plume was directed away from the districts by southerly wind (B87). Steingrímsson's descriptions indicate that this activity lasted for a considerable time, possibly throughout the spring of 1784. Activity at Austur-Landnorðursgjá was observed off and on through the year 1784 and in the winter 1785, especially from the Öræfi district. The last day when fires were seen at Grímsvötn was 26 May 1785 (B89).

Strong earthquakes were felt in the Fire districts sometime in February 1784 and were described by Steingrímsson as follows:

"After a long period of freezing and heavy winds which lasted through January, strong earthquakes were felt again, though different than previous ones. Some moved the earth slightly up and down, others travelled like oceanic waves from northwest to southeast. The frozen ground cracked with the sound of thumps and claps." (A26)

The cracks were most numerous in the Fljótshverfi district and Steingrímsson notes that the spring water in the Fire districts, which had been strongly contaminated up to this time, tasted much better after these earthquakes.

DISCUSSION

NATURE OF ERUPTIVE ACTIVITY AND RELATED PHENOMENA

The Laki eruption began on 8 June 1783 and 7 February 1784 was the last day when activity was noticed at the fissures. This day is taken to mark the end of the Laki eruption and accordingly the eruption lasted for 8 months. Despite the termination of activity on the Laki fissures, activity continued at the Grímsvötn volcano until 26 May 1785, indicating an ~2 year duration for this eruption episode on the Grímsvötn volcanic system (Thordarson and Self, 1993).

For almost 200 years the accepted view on the progress of the Laki eruption was based on the idea put forth in 1794 by Sveinn Pálsson (see Thordarson, this issue). The view was that the eruption featured two main eruption episodes, the first commencing on 8 June on the fissures to the southwest of Mt. Laki and a second one that commenced on 29 July on the fissures to the northeast of mountain (Figure 3). Both episodes where thought to have begun with explosive

activity that was followed by a longer-lasting phase of quiet lava effusion (i.e., Helland, 1886; Thoroddsen, 1879, 1894, 1925; and Thorarinsson, 1967, 1969).

However, studies of the proximal tephra stratigraphy have shown this view to be oversimplistic and that the Laki eruption featured at least 10 distinct eruption episodes (Thordarson and Self, 1993). Furthermore, the Grímsvötn volcano erupted intermittently from June 1783 through May 1785, adding at least four eruption episodes to the Laki-Grímsvötn event (Table 2). These results are substantiated by the contemporary descriptions (Thordarson, 1990, 1991), which provide strong evidence for the episodic nature of the Laki eruption as indicated by repeated occurrences of earthquake swarms, explosive activity and lava surges. The nature and association of these phenomena, as revealed in the contemporary accounts, will now be considered in more detail.

SEISMIC ACTIVITY

Three facets of the seismic activity associated with the Laki eruption have important implications. Firstly, the contemporary accounts only document earthquakes that were strong enough to be felt by the inhabitants at a distance of 30–80 km from the Laki fissure. Secondly, they indicate that earthquakes occurred in swarms that often lasted for days. Thirdly, these earthquake swarms commonly preceded or coincided with the onset of explosive activity and increased lava production at the vents (Table 2).

The evidence indicates that the earthquakes associated with the Laki eruption were readily detected at distance of >30 km from source vents, implying that their magnitude was $\geq$4 on the Richter scale (Brandsdóttir, 1992). Consequently, rifting of brittle crust rather than volcanic tremor (sensu stricto) is a more likely source for these earthquakes.

Also, despite a significant difference in periodicity, the episodic occurrence of intense earthquake swarms in association with increased activity at the Laki fissures shows a strong resemblance to the pattern observed in recent volcano-tectonic rifting episodes in Northern Iceland (Bjornsson *et al.*, 1977; Brandsdóttir and Einarsson, 1979, Brandsdóttir, 1992). Consequently, it is logical to conclude that the 3–4 weeks of gradually increasing earthquake activity that preceded the Laki eruption mark the onset of rifting within the Grímsvötn volcanic system and the initial emplacement of the Laki feeder dyke. By the same token, the subsequent earthquake swarms represent ongoing rifting that resulted in gradual northeast extension of the erupting fissures (Thordarson and Self, 1993).

The strong earthquakes felt in the Fire districts in February 1784 are worthy of further note. These earthquakes occurred towards the end or after cessation of activity at the Laki fissures. Furthermore, Steingrímsson describes these earthquakes as being different from those clearly associated with the eruption and it is very likely that these earthquakes were not directly related to the activity at the Laki fissures. It is interesting that strong earthquakes were also felt on the Reykjanes peninsula in Southwest Iceland on 24 and 25 February 1784 (Lievog, 1784). It is possible that these earthquakes resulted from larger-scale dislocations on the South Iceland Seismic Zone (SISZ) and may have been the precursors to strong earthquakes that occurred on the SISZ in August that year, causing significant damage to structures and buildings in the region. Furthermore, it is difficult to believe that this sequence of events (i.e., the Laki eruption and subsequent earthquakes on the SISZ) is a random occurrence because not only do they show close association in terms of time, but occur on structures that are closely linked geologically. The SISZ is a complex zone of faulting linking the overlapping sectors of the Western and the Eastern Volcanic Zones and thus it is conceivable that the earthquake activity on the SISZ was triggered by the Laki-Grímsvötn volcano-tectonic episode (Stefánsson and Halldórsson, 1988; Gudmundsson, 2000).

EXPLOSIVE ACTIVITY AND TEPHRA DISPERSAL

Although the tephra fall deposits only amount to 2.7% of the erupted magma volume (Thordarson and Self, 1993), the explosive activity at the Laki fissures was significant and should not be overlooked. The magnitude of the explosive activity at Laki gains a new perspective when it is acknowledged that the 0.4 km^3

of tephra produced by the eruption is greater than the cumulative tephra volume from all four 20th Century Hekla eruptions. The Laki tephra deposit covered 7200 km^2 within the 0.5 cm isopach. For comparison the area within the 0.5 cm isopach for the 1947 and 1991 Hekla eruptions is ~2000 km^2 and 485 km^2, respectively (Thorarinsson, 1976, Larsen *et al.*, 1992). The Laki eruption plumes also dispersed tephra as far as the Faeroe Islands, Scotland and mainland Europe, implying that an area of ~750,000 km^2 may have been affected by tephra fall from Laki. Information on the timing and dispersal of tephra falls provides valuable information on the source and nature of explosive activity during the Laki-Grímsvötn eruptions. This facet of the eruption has been analysed in detail by Thordarson and Self (1993) and thus only the key results are reiterated here.

In the first 3 months of the eruption, the contemporary accounts report fifteen occurrences of tephra fall in association with the Laki-Grímsvötn eruptions. Eight of the reported occurrences refer to tephra falls that directly affected the Fire districts and five indicate rain out of tephra in the highlands above the Fire districts (Figure 5). The last two are reports of tephra fall elsewhere in Iceland, one near Vestmannaeyjar off the south coast and another in Skagafjörður, Northern Iceland (Figure 1, inset).

Eight of the reported tephra falls originated at the Laki fissures (Figure 5a–f). On five occasions the tephra was spread over the Fire districts, whereas on three occasions the tephra fall was confined to the highlands to the west and north of the fissures. Each of these tephra falls are derived from different fissure segment on the vent system and the tephra stratigraphy indicates a systematic northeast propagation of the explosive activity with time. Furthermore, textural studies of the tephra fall units that make up the proximal deposit show that at least five of the fall units were produced by explosive activity of subplinian character whereas two were formed by phreatomagmatic activity (Thordarson and Self, 1993).

Sightings of fire fountains on 8 June indicate that at the onset of the eruption the activity was confined to the vents on fissure 1 (B8; Figure 3). The tephra that fell in the Fire districts on the first day was produced by explosive activity on this fissure (Figure 5a). The two additional fire fountains noticed on 11 June indicate a northeast extension of the vent system and were linked to formation of fissure 2 (B18; Figure 3). The following night explosive activity on these fissures produced a tephra fall that was dispersed to the west-southwest toward the Mýrdalsjökull glacier (Figure 5a). The tephra that fell in the Fire districts on 14 June contained noticeably more of Pele's hair than previous falls (B27–B29) and the tephra stratigraphy shows that it is derived from fissure 3 (Figure 3 and 5). Judging from the contemporary chronicles each of these tephra falls lasted only for several hours (B4–5, B29), indicating that the subplinian phases were short-lived; peaking abruptly and followed by rapid and steady decline in explosive intensity. Contemporary observations show that in the period June to August the eruption columns above the Laki fissures rose to heights greater than 8.5 km (B71). These observations are compatible with model calculations, which indicate that the subplinian eruption columns were at least 11-13 km high and that the principal tephra fallouts occurred from high altitude plumes. The vigour of the explosive activity is verified by the abundance of Pele's hair in these tephra falls (e.g., B3–4, B27–29), because its presence implies very high eruption velocities in gas-charged fire fountains (Shimozuru, 1994). This evidence, along with extremely effective vent degassing, is taken to indicate eruption by high velocity gas-rich jets that drove the subplinian explosive activity (Thordarson *et al.*, 1996).

Again subplinian tephra fall occurred in the Síða district on 9 July and continued through the 10th (B48–B50). This tephra fall appears to have had a southeasterly dispersal because it did not reach the Meðalland district (Figure 5d). The proximal tephra stratigraphy shows that at this time all of the fissure segments southwest of Mt. Laki erupted explosively and that a significant amount of tephra was dispersed to the north of the fissures. This dispersal direction is consistent with the indicated weather pattern for 11–12 July on reconstructed synoptic weather maps for the North Atlantic region (Kington, 1988). Thus, the explosive activity most likely continued through 11 and 12 July.

Two more subplinian explosive phases are indicated by the available data. There are no records of the first one in the historic accounts, but a subplinian fall unit derived from fissure 7 is preserved in the proximal tephra deposit at the kipuka Innri-Eyrar (Figure 3). The Fissure 7 subplinian fall unit rests directly on the phreatomagmatic fall unit produced by explosive activity on fissure 6 (see below) and therefore was formed later, most likely towards the end of August or at the very beginning of September. The second phase took place around 7 September as is indicated by records of tephra fall near Vestmannaeyjar. At the time the wind was blowing from the northeast (Kington, 1988) and the tephra-laden plume would have been carried directly over the Mýrdalsjökull glacier. Thus, no or very little tephra would have fallen in the Fire districts (Figure 5f). This tephra fall unit and later falls (if they occurred) have not been identified in the proximal deposit, in part because the three north easternmost fissures of the Laki vent system are completely surrounded by lava (Figure 3). Consequently, the proximal part of the tephra fall that may have been produced by the explosive activity on these fissures is either buried beneath the lava or completely removed by erosion or both.

The explosive activity that commenced on 25 June and peaked on 27–28 June produced a black eruption plume that "twisted and spun over the mountains forming bolsters" that dispersed "sandy" tephra over eastern part of the Fire districts (B41–43, Figure 5c). This description of the plume is consistent with our knowledge of ash-laden and water-saturated plumes that are formed by phreatomagmatic eruptions (Thordarson, 1991). On the basis of the proximal stratigraphy and timing of events, this tephra fall is correlated with the phreatomagmatic fall unit that originated from the tuff cone that is located on the central part of fissure 4 (TC1 on Figure 3).

Similar plume and tephra-fall was dispersed over the eastern parts of the Fire Districts on 29 July (B62, Figure 5e). Phreatomagmatic explosions that produced the tuff cone on fissure 6 (TC2 on Figure 3) produced this tephra fall. This explosive phase marks a significant change in the eruption because it coincides with a shift in the activity at the Laki vents. From this time on, the main activity was centred on vents to the northeast of Mt. Laki.

Four of the reported tephra falls are considered to be from explosive activity at the Grímsvötn volcano. The tephra fall reported on 18 July is undoubtedly from Grímsvötn and this is clearly indicated by Steingrímsson in his description of the eruption (B52). The westerly dispersal and the aireal coverage of the tephra fall on 21 June, 19 July and 14 September rule out origin at the Laki fissures and point toward a source farther east (i.e., B34, B54, B70; Figures 5b and 5d). In light of other evidence presented above (see p. 18–19) showing that eruptions at the Grímsvötn volcano coincided with the activity at the Laki fissures, it is reasonable to assume that the source of these tephra falls was explosive activity at Grímsvötn.

The reports of tephra falls clearly show that the explosive activity at the Laki fissures was episodic and not simply confined to the beginning of the eruption as thought previously (Helland, 1886; Thoroddsen, 1879, 1894, 1925; and Thorarinsson, 1967, 1969). The records appear to give a realistic representation of periods of vigorous explosive activity at the vents, because in general terms their occurrence conforms well to the established tephra stratigraphy and the dispersal of individual fall units (Thordarson and Self, 1993). These conclusions are strengthened by the perceptible synchronisation of earthquakes, explosive activity and increase in lava production (Figure 6, Table 2).

THE LAVA SURGES AND OTHER FLOW RELATED PHENOMENA

Steingrímsson's meticulous descriptions of the Laki lava as it flowed across the plains in front of the Síða highlands are truly remarkable. Not only do these descriptions provide accurate information about the advance of the lava but also are a valuable source for assessing the flow dynamics. A detailed analysis of these descriptions and their implication for the characteristic emplacement mechanism of the Laki lava is beyond the scope of this study and will be presented elsewhere. However, two aspects of Steingrímsson's descriptions are particularly important for evaluating the progress of the Laki eruption; the occurrences and timing of lava surges and descriptions revealing the

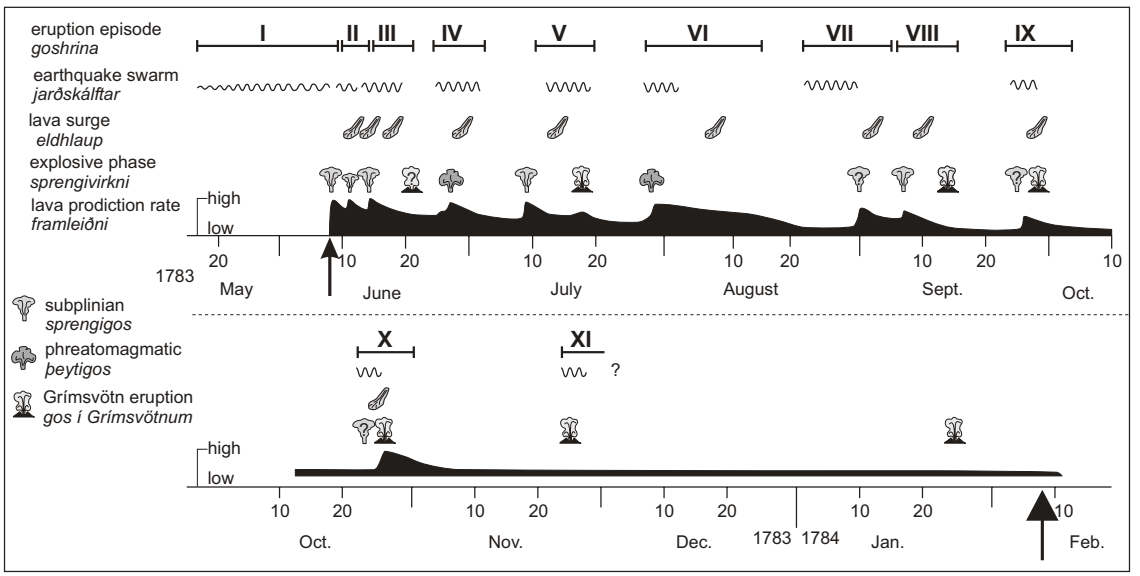

Figure 6. Schematic illustration of sequence of events during the Laki-Grímsvötn eruptions. Extent of earthquake swarms is indicated by wiggly lines; fluctuations in lava discharge shown by shaded area (not to scale); eruption clouds denote explosive activity at Laki fissures; eruption clouds with a cone at the base denote explosive activity at Grímsvötn volcano; arrows indicate onset and termination of Laki eruption. The solid bars show the extent of each eruption episode, labelled I, II, III etc. Modified from Thordarson and Self (1993). – *Myndræn framsetning á framvindu Skaftárelda.*

position of lava flow fronts at various times during the eruption.

Descriptions of recurring "eldhlaup" (i.e., lava surges) from the Skaftá River and the Hverfisfljót River gorges clearly indicate periodic but abrupt increase in lava flow rates. These surges travelled at velocities in excess of 6 km per day (Thordarson and Self, 1983) and resulted in rapid advances of the active lava fronts that tapered off over several days (e.g., Appendix C and Figure 5b). It is noteworthy that the lava surges occurred throughout the eruption and in each case they emerged from the gorges 3-5 days after a major explosive phase on the Laki fissures and the Grímsvötn volcano (Table 2, Figure 6). This synchronisation in the activity strongly indicates that these lava surges represent episodic increase in lava production at the fissures and hence in the magma discharge.

The contemporary accounts do not give unambiguous information about the mechanism by which these surges travelled from the fissures to the active flow fronts. However, certain inferences can be made about the most likely transport mode from flow emplacement structures and the overall volcanic architecture of the Laki lava flow. The Laki lava flow consists of numerous lava lobes, which range from meters to kilometres in length and decimetre to >20 m in thickness (Thordarson and Self, 1993; Keszthelyi *et al.*, 2000). Even so, nowhere on the lowlands in front of the Skaftá River and Hverfisfljót River gorges does the flow field feature stacked lava flows as defined by Self *et al.,* (1993), as would be expected if each of the lava surge had produced their own surface flow originating at the vents. Furthermore, tumuli, tumulus ridges, lava rise pits, and lava rise plateaus are common surface structures in the Laki lava flow field and filled or drained lava tubes have been found in various parts of the lava (Figure 7a–e; Thordarson and Self, 1993; Wood *et al.*, 2001). Studies of the flow top

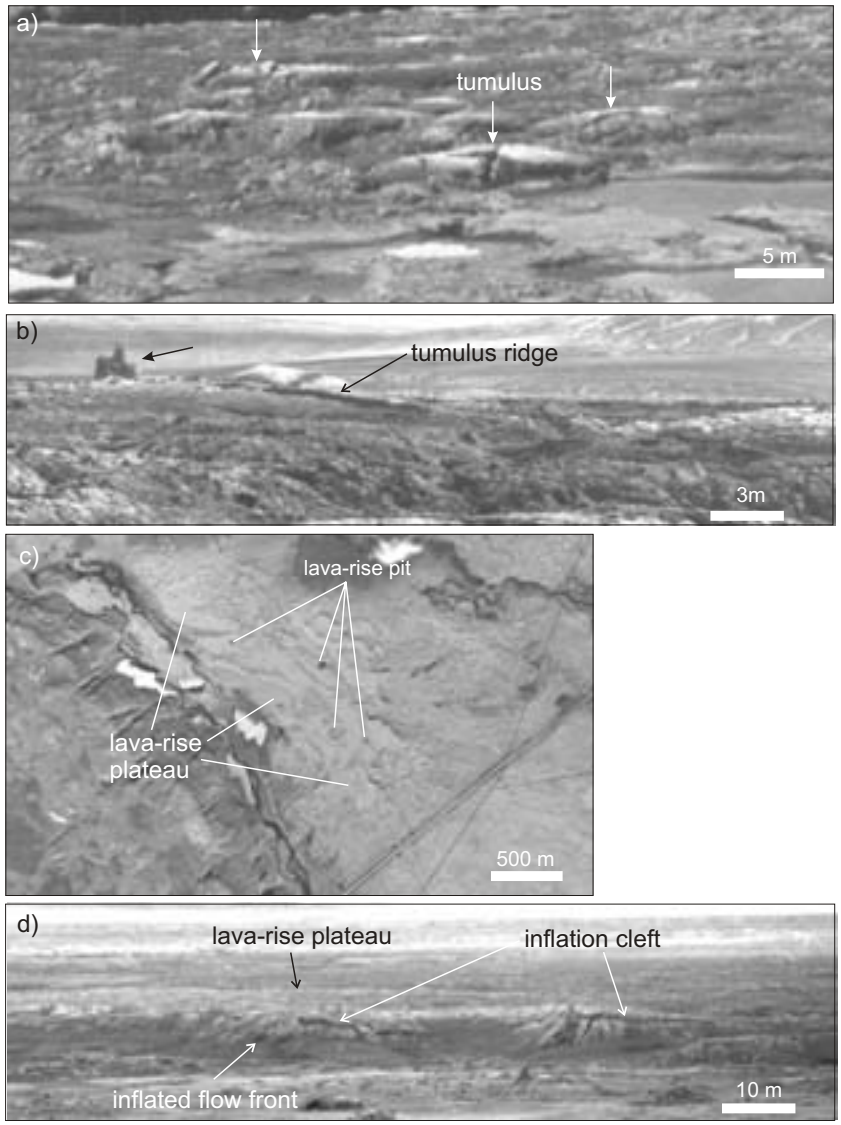

Figure 7. Flow structures in the Laki lava flow field indicative of insulated lava transport and flow inflation (i.e., endogenous growth). Location of each photograph is shown on Figure 2: (a) tumuli, formed when flow inflation locally exceeds that of the surrounding lava, for example above a pool in a subsurface lava pathway (Walker, 1991; Hon *et al*., 1994). (b) A tumulus ridge, which are the surface manifestation of an inflating pathway (e.g., Thordarson, 2000). The hornito (arrowed) was formed by a rootless eruption through the central cleft; (c) lava rise plateaus and lava rise pits (aerial view). The plateaus are formed by uniform inflation of broad pahoehoe sheet lobes, whereas the pits are localized areas where the rate of inflation was lower than in adjacent parts of the flow (Walker, 1991), and (d) inflated margin of a lava rise plateau, the cracks are inflation clefts.

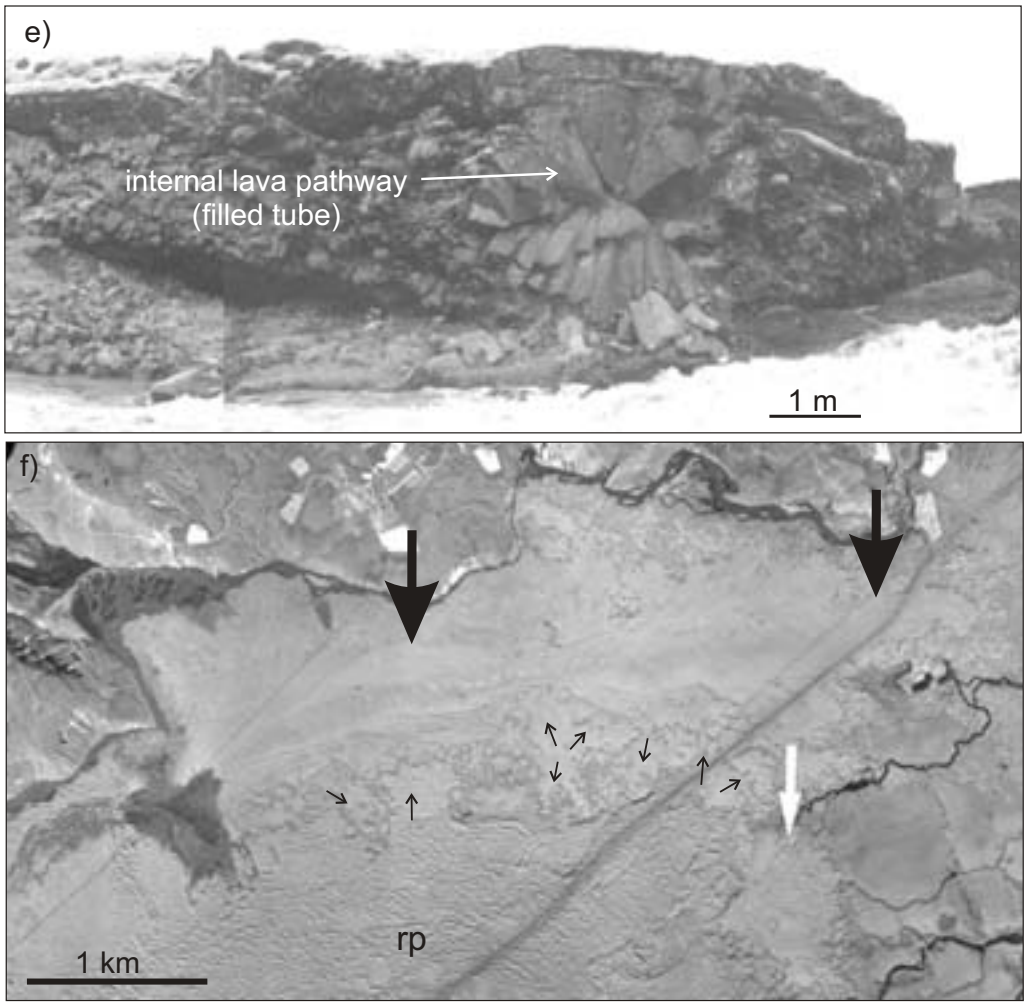

Figure 7. cont. e) An internal lava pathway (i.e., filled tube) in a Laki sheet lobe; f) a large frontal breakout (large black arrows) near the edge of the Laki flow field (rough textured area, labelled rp). This breakout burst out from the active flow front on 1 July 1783 and formed a ~5 km long pahoehoe sheet lobe in six days. It is crowned by numerous smaller breakouts along the lobe margins (the speckle-textured areas). At the southern margin of the lobe these smaller breakouts are mingled with breakouts from the main flow field (small arrows point in direction of flow), indicating that lava was transported through both the main flow field and the sheet lobe at this time. The main flow field is rubbly pahoehoe covered by thick flow top rubble that was piled up into concentric ridges oriented perpendicular to flow. The interior of this flow was well insulated and hot because it fed numerous frontal breakouts of pahoehoe morphology (e.g. large white arrow and small black arrows). *–Flæðistrúktúrar í Skaftáreldahrauni sem bera vitni um einangrað flæði undir samfelldri skorpu og hraunris.*

rubble (Keszthelyi *et al.*, 2000), which covers about one half of the Laki lava, indicate that it was initially formed by break up of coherent and stationary pahoehoe crust as a result of surging within the underlying lava. This process exposes the incandescent flow interior and at this stage the rubble grows in thickness; first by autobrecciation of incandescent lava and then by the moving lava as it piles the rubble up into concentric pressure ridges oriented perpendicular to the flow direction (e.g. Figure 7f). However, the base of these rubbly lavas is typified by smooth pahoehoe surface, showing that they have a hybrid morphological character that falls between the two end-member basalt lava flow types, a'a and pahoehoe. However the emplacement mechanism of these lavas differs significantly from that of a'a and pahoehoe and therefore it is considered to be a distinctive flow type, named rubbly pahoehoe by Keszthelyi and Thordarson (2000).

All of the flow structures mentioned above are indicative of endogenous growth, suggesting that insulated lava transport and growth by inflation played an important role during the emplacement of the Laki lava (e.g. Thordarson and Self, 1993; Keszthelyi *et al.*, 2000). It is, therefore, reasonable to assume that the lava, including the surges, was transported from the vents to the active flow fronts within preferred internal pathways (i.e., master lava tubes). Such pathways were presumably established early on during emplacement of the lava in the Skaftá River gorge, and later in the Hverfisfljót River gorge, and subsequently lengthened as the lava flow field grew in size. The lobed architecture of the Laki flow field is also consistent with this view, because compound flows are one of the characteristic features of endogenous flow emplacement (e.g., Walker, 1991; Hon *et al.*, 1994; Mattox *et al.*, 1993). Each lobe is produced as a breakout from the main pathways or pre-existing lobes at the active flow front or onto the lava surface (Figure 7f), resulting in incremental lengthening and thickening of the flow field.

A CONCEPTUAL MODEL ON THE PROGRESS OF THE LAKI ERUPTION

The above analysis of the contemporary accounts clearly shows that the Laki eruption featured distinctive eruption episodes reflecting periodic increases in the magma discharge (Figure 6). Each episode began with an earthquake swarm of increasing intensity that was followed by vigorous explosive activity at the fissures and sudden increases in outflow of lava from the fissures. The seismic swarms generally lasted for several days to a week, with the exception being the first which lasted for 3–4 weeks. Each earthquake swarm was followed by a short-lived subplinian or phreatomagmatic explosive phase leading into a longer-lasting phase of lava fountaining and effusive activity. A surge of lava emerged from either the Skaftá River or Hverfisfljót River gorge 3–5 days after the beginning of each explosive phase. The events described above define an eruptive episode and all in all Laki event featured 10 such episodes (Figure 6). The Laki cone-row is composed of at least 10 en echelon fissures, trending N47–48°E (Figure 3). Using tephra stratigraphy, coupled with descriptions on the location and timing of explosive activity and lava surges, each of the ten eruption episodes is linked to the opening of a new fissure segment and the stepwise propagation of the locus of activity from the southwest to the northeast (Thordarson and Self, 1993). In this context it is worth noting that there is a perceptible increase in the frequency of eruptions at Grímsvötn during fall 1783 and that the volcano was active through to May 1785, adding four eruption episodes to the 1783–1785 activity on the Grímsvötn volcanic system (Table 2). It is conceivable that these trends are linked. The obvious synchronisation in the activity at the Laki fissures and the Grímsvötn volcano indicates that both eruptions resulted from the same volcano- tectonic event. However, a range of evidence show that the magma erupted at the Laki fissures is derived from a large deep-seated reservoir located at the crust-mantle boundary, whereas the eruptions at Grímsvötn occurred from a shallow crustal magma chamber (Gudmundsson, 1987; Sigmarsson *et al.*, 1991; Thordarson and Self, 1993). Thus, the trends mentioned above may indicate a gradual restoration in the flow of magma from the deep-seated reservoir to the shallow magma chamber beneath the Grímsvötn volcano.

CONCLUDING REMARKS

This summary on the course of events during the 1783–1785 Laki-Grímsvötn eruptions is primarily based on an analysis of the information contained in the contemporary accounts, although some of the conclusions are reinforced by field observations. The 1783–1784 Laki eruption is a classic example of basaltic flood lava eruptions and the only one that was observed and described by man. Consequently, the Laki accounts provide us with unprecedented and vital insight into the nature and progression of flood lava eruptions. This data has been applied successfully in studies of past flood lava eruptions, not only here on Earth but also on the other planets (e.g. Thordarson and Self, 1998; Keszthelyi *et al*., 2000).

Our work has produced results that differ from those put forth previously by other geologists (e.g. Thoroddsen, 1879, 1925; Helland, 1886; Thorarinsson, 1967; 1969). This difference can in parts be explained by our approach, because for the first time the information contained in the written records have been systematically evaluated according to the processes they describe. This has allowed us to present a detailed reconstruction of the Laki eruption and associated activity at the Grímsvötn volcano. In the last thirty years our understanding of volcanological processes has improved significantly. Consequently many of the original Laki descriptions have gained a new perspective and been re-interpreted in light of latest advances. One purpose of this work is to provide the volcanological community with the information contained in the original accounts on the progress of the 1783–1785 Laki-Grímsvötn eruptions such that those who are willing can themselves evaluate our results and conclusions. Furthermore, we hope that this contribution will provoke further studies on this remarkable event.

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ÁGRIP

Skaftáreldar 1783–1784, ásamt þeytigosum í Grímsvötnum voru afleiðing tveggja ára umbrotahrinu í Grímsvatnakerfinu frá miðjum maí 1783 til 26. maí 1785. Skaftáreldagosið er, á eftir Eldgjárgosinu 934–940, annað stærsta flæðigosið á sögulegum tíma og mestu náttúruhamfarir sem sögur fara af á Íslandi. Samtímaheimildir veita nákvæmar upplýsingar um atburðarásina í þessum umbrotum, sérstaklega hvað varðar framvindu Skaftárelda. Við höfum gert ítarlega úttekt á öllum aðgengilegum frásögnum sem varpa ljósi á atburðarás og eðli þessara umbrota. Til þess að fá heildaryfirlit yfir þessar upplýsingar voru frásagnirnar skráðar í tímaröð og þeim raðað niður í flokka eftir þeim atburðum sem fjallað er um í heimildunum, þ.e. skjálftavirkni, gjóskugosvirkni, hraunstreymi og áttaskyni (sjá viðauka, töflur A til D). Þessar upplýsingar voru notaðar til þess að kryfja til mergjar einstaka atburði og gosferli í Skaftáreldum. Helstu niðurstöður athugana okkar sýna að umbrotin á Grímsvatnakerfinu gengu á með hrinum. Samtímaheimildir greina frá að minnsta kosti 14 goshrinum. Tíu af þessum goshrinum voru sjálfir Skaftáreldarnir, þar sem sérhver hrina hófst með skjálftum og öflugu þeytigosi. Í kjölfar hverrar hrinu jókst hraunrennslið verulega frá gosstöðvunum niður á láglendið. Grímsvötn gusu að minnsta kosti sex sinnum á meðan Skaftáreldar stóðu yfir og tvívegis eftir að eldar kulnuðu á gossprungunum inni á Síðumannaafrétti (þ.e. apríl 1784 og maí 1785). Í fjórum tilvikum var þeytigos í Grímsvötnum samfara hrinu á Skaftáreldasprungunni og telst því vera hluti af þeim goshrinum. Í hinum fjórum tilfellunum takmarkaðist aukin gosvirkni aðeins við Grímsvötn og af þeim sökum eru þessi gos talin sem sérstakar goshrinur.

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APPENDIX

The appendix contains English translations (by the senior author) of original text in the contemporary accounts containing information on seismicity (Table A), explosive activity (Table B), lava flows (Table C), and sense of directions in the Fire districts (Table D). The Index number links to citation numbers in the text. The first number in the Source column refers to the numbered citations listed below and the latter indicates the page number in the original source for each quotation: 1. Steingrímsson, 1783a; 2. Steingrímsson and Ólafsson, 1783; 3. Steingrímsson, 1783b; 4. Steingrímsson, 1788; 5. Eiríksson, 1783b; 6. Björnsson, 1783; 7. Thorarinsson, 1783; 8. Pálsson, 1783; 9. Hólm, 1784; 10. Stephensen, 1785; 11. Pálsson, 1794; 12. Stephensen, 1783; 13. Pétursson, 1783; 14. Thorsteinsson, 1783. Full reference to the original sources is given in the bibliography in the back. Note that the term Vesturgjá is a synonym for Útnorðursgjá and similarily Austurgjá is a synonym for Landnorðursgjá.

Table A: Seismic activity

Date	Index	Source	Quotation
19 April–29 May	A1	5, p. 274	In mid-May I [Jón Eiríksson at Ljótarstaðir in Skaftártunga] *felt some earthquakes*, during nights especially. I kept this to myself and did not hear any others speak of it until Ascension Day when *some earthquakes were felt* in the upper part of Skaftártunga. From then on *earthquakes increased (in frequency and intensity)* so people slept in tents out on open fields.
Early June	A2	13, p. 455	...but the farm Ásar in Skaftártunga almost collapsed from the *intensive earthquakes*, which were associated with this eruption.
1 June	A3	2, p. 58	This day was the beginning of our afflictions, when *strong earthquakes were felt*, not only here in Síða, Landbrot, Meðalland and Álftaver, but also in Mýrdalur in the west and Öræfi in the east. *These earthquakes increased in frequency and intensity) the following week* and were mostly felt in the mornings and the evenings.
9 June	A4	4, p. 9	The night before *strong earthquakes and tremors* were felt.
9–11 June	A5	5, p. 274	The *earthquakes increased steadily* during the first four days of the eruption. [until 11 June]
10 June	A6	2, p. 58	...*earthquakes continued to be felt*... [i.e., in the Síða district]
11 June	A7	2, p. 59	All that day and the following night *strong earthquakes were felt*.
13 June	A8	4, p. 9	...cracking and thuds were heard behind the mountains in the northwest followed *by earthquakes* [i.e., associated with activity at Útnorðursgjá]
14 June	A9	2, p. 60	The lava emerged out from the Skaftá River gorge and along Árfjall mountain with such a murmur that the *earth trembled and vibrated* along with continuous sparks of fire and claps of thunder, so few people rested or slept that night.
15 June	A10	4, p. 11	All that day and the following night *earthquakes were felt*.
16 June	A11	4, p. 12	The *din* [tremor?] and the cracking, the fires and the stench along with the *earthquakes north of the mountains bordering Síða* was so frenzied, that no one was sure whether this settlement was safe.
18 June	A12	4, p. 13	...again the lava surged out of the western fissure, filling up the Skaftá River gorge which was both deep and wide, and accompanied by *intense earthquakes, tremors* and frequent thunder claps. ...This day and night the thunderclaps were so extensive that everything *trembled and vibrated and earthquakes caused cracking noise from every house timber*.
19 June	A13	2, p. 62	Weather was calm, but *earthquakes were frequent and hard*.
23–26 June	A14	2, p. 63	...lava emerged from the Skaftá River gorge at steady rate accompanied by earthquakes and thunder and lightning were observed all around.
30 June	A15	4, p. 19	...calm weather, thunderclaps and *earthquakes* along with a boiling noise from the fissure.
14 July	A16	4, p. 21	...for the fourth and last time a lava surge emerged out from Vesturgjá along with boiling, creaking and cracking noises and *such a din* that everything appeared to be going out of control, [din = tremor?].
17 July	A17	4, p. 22	What was left of *the livestock crowded together* out of their dismay or ran around shrieking in their own sound and some dropped dead where they stood. [old Icelandic accounts show that when animals gathered in groups, it is indicative of seismic activity]
18 July	A18	4, p. 22	*The din* [tremor?] was so frenzied that I [Jón Steingrímsson] thought everything would be demolished.
20 July	A19	4, p. 22	...*continuous earthquakes*.
1–3 Aug.	A20	4, p. 26	...the same boiling was continuously heard from this gjá along with *earthquakes*, thunder, lightning and continuous outpouring of lava [gjá = Landnorðursgjá].
23–31 Aug.	A21	4, p. 28	...the eruption proceeded in similar fashion, except *intensive earthquakes* were felt and claps were heard from Austurgjá.
26 Sept.	A22	4, p. 29	...*intensive tremors or rather earthquakes* were felt again, especially in the eastern part of Síða and in Fljótshverfi, which was followed by increasing activity and lava effusion to the north of the mountains...
24 Oct.	A23	4, p. 30	This day *earthquakes started again* and strong stench was smelled from east-northeast...
Nov.	A24	4, p. 31	...*occasional weak earthquakes* were felt in Síða.
24 Nov.	A25	4, p. 31	*A strong earthquake* was felt in Meðalland, but its intensity was much less here at the foot of the scarp.
Jan.–Feb. 1784	A26	4, p. 32	After a long period of freezing and heavy winds that lasted through January, *strong earthquakes were felt again, though different than previous ones*. Some moved the earth slightly up and down, others travelled like oceanic waves from northwest to southeast. The frozen ground cracked with sound of thumps and claps.
14–25 Aug. 1784	A27	4, p. 35	In the summer 1784, *14 and 15 August weak earthquakes were felt here in Síða*, which were related to activity at the north-northeastern fissure, and the last one occurred on the 25 August. After that such activity [i.e., earthquakes] was not perceived until it recurred in the Rangárvallasýsla and Árnessýsla were it ruined many farmhouses.

Table B: Explosive activity

Date	Index	Source	Quotation
spring 1783	B1	2, p. 58	During this time people [in the Fire districts] often noticed a *bluish smoke over the ground*, and many thought, as became evident later on, that *it was from a volcanic eruption*. Later that spring travellers from Reykjanes told us that the ongoing submarine eruption at Helgusker southwest of Reykjanes was not the only one. The crew on a brig coming from Denmark *saw a column of fire in the mountains or the glaciers north of us* [i.e., the Fire districts], as they passed the southern coast on their way to Hafnarfjörður. [Thoroddsen (1908–1911) states that the submarine eruption off Reykjanes was seen in early May 1783 by a crew of a brig that was on its way to Hafnarfjörður in southwestern Iceland. Steingrímsson's description implies that it was the same crew that saw the columns of fire above the Fire districts, suggesting an eruption in the area in early May.]
spring 1783	B2	10, p. 11	...the water level was unusually high in the Skaftá River and *the water dirty and ill-smelling*.
8 June	B3	1, p. 272	After a period of intensive earthquakes, on 8 June *an eldgjá began erupting* in the so-called Síða highlands due southwest of Úlfarsdalur glacier. *Volcanic ash and hairy material* [Pele's hair] *was dispersed over this district* [i.e., Síða] *so footprints marked in it on the third day* of the eruption. The heavy rain which fell from the eruption from the fire and smoke columns that rose from the fissure, which *now exposed itself by numerous columns of fire*, contained salty and sulfur smelling water which caused smarting in the eyes and on the skin.
8 June	B4	2, p. 58	...about 9 a.m. *a black plume emerged from north*, dispersed over Síða so it became dark inside our homes. So much volcanic ash fell out of the plume, that *footprints* marked in it. The ash resembled the remains of burned coal and contained *glittering hairs* that were easily crushed between the fingers. Such an ash fell here many times after that. This plume was directed away later that day by southerly breeze.
8 June	B5	4, p. 8	...about 9 a.m. *a black sand-bearing mist and a plume* emerged north of the highest mountains bordering the Síða district, so big that in a short time it spread over Síða and part of Fljótshverfi. The cloud caused it to be *dark inside our homes* and so much volcanic ash fell out of the cloud that footprints marked in the ash deposit. A drizzle that fell from the plume on this day in Skaftártunga was so laden with ash that it resembled ink. Later that day the plume was kept away by southeasterly breeze.
8 June	B6	3, p. 69	...*a dense ashy plume* fell over us, so it became *dark inside* houses and *footprints* marked in the deposit. For the next *three days* the ash-fall was accompanied by heavy rainfall; and occasionally a strong stench, like in a steamy sulfur mine, was felt. The *rainwater* was salty and bitter and the drops felt like hot brine when they fell on bare skin.
8 June	B7	5, p. 274	On Whitsunday I first saw a *fire column and smoke* northeast from my home [Ljótarstaðir in Skaftártunga], but north of Síða, which were thought to be located within the glacier where Grímsvötn are to be found. ...*No ash* was observed to fall here [in Skaftártunga], but in Síða the ash deposit was so thick that *footprints* marked in it when someone walked over it. The ash was washed into the ground by the rain that followed the ash-fall.
8 June	B8	6, p. 296	*Three columns of fire* were seen rising up through the darkness from the central part of Síða, or to the north of the farm Mörtunga that is inland from the farm Prestbakki. [The trace of a line from Prestbakki to Mörtunga is the direction toward the westernmost craters on the Laki cone row located near Hnúta Mountain, see Figure 2].
8 June	B9	9, p. 1	During that time large smoke and steam columns were constantly seen in the wastelands called Síða highlands to the north of these districts: Síða, Landbrot, Meðalland, Álftaver, NW of Fljótshverfi, but NE of Skaftártunga. There were three columns of fire of which the westernmost and the northernmost was the largest one. The former one was seen in so called *Úlfarsdalur Valley*, just east of Skaftá River gorge according to trustworthy documents; the other two were seen close to the Hverfisfljót River gorge. These three before mentioned columns of fire, when they were highest, accumulated into one and reached such height that they were seen from more than 34 miles away [Danish mile = 7532.48 m; distance = 260 km]. Most of the time these fires were screened out of sight by mist and smoke. [This description is a brief summary of the eruption by S. Hólm. The three columns of fire indicate to the three eruption sites seen from the Fire districts and referred to as Útnorðursgjá, Landnorðursgjá and Austur-Landnorðursgjá by Steingrímsson].
8 June	B10	9, p. 6	On 8 June the before mentioned eruption began ...huge smoke and ash cloud emerged with great force, cracking sounds and rumbles, carrying an enormous amount of sulfurous material, sand, ash and scoria. Part of the *tephra* was dispersed over the *pasture and the mountainous wasteland*, but another part of it was carried over the *rural settlement* according to how the wind was blowing each time. The air was filled with such an amount of sulfurous haze and sandy dust that it was *often impossible to read and write during mid-day*. In those districts that where darkened by the sandfall, which partly consisted of *volcanic ash and glowing pumice and partly of ink colored mud-like material and hairs*, some of which were rolled up into small bundles, while others resembled wreaths and those caused the greatest damage. *On June 8, the above described ash deposit was dispersed over Síða and some of the other districts and this recurred number of times*. On the third day of the eruption the *columns of fire*, which continuously rose from the fissure, were seen clearly as *numerous flames* and at the same time strong rumbling and cracking sounds were heard from the same place.
8 June	B11	10, p. 13	In the morning of Whitsunday, 8 June, *the weather was still calm and bright*. But around 9 a.m. a *large black plume* was seen rising into the air north of here and spread over the Síða district. This plume was not seen from the farms, aligned along the east-west trending scarp bordering the Síða district, until it was almost over the district. However a few people from the Landbrot district on their way to church at Kirkjubæjarklaustur saw *many columns of smoke* rise up over the mountains in the north and how they accumulated into one to form the *dark sandy plume*.
9 June	B12	2, p. 58	...same weather [as on 8 June] with southeasterly breeze, the *dark sandy plume* was now seen clearly in north above the mountains.
9 June	B13	4, p. 9	...*the plume rose continuously*. That night heavy rainfall came down from it.
10 June	B14	2, p. 58	...*torrential rain from the plume that now continuously rose higher and higher* by the day. The rain water was loaded with before mentioned *sandy ash and hairs*, light blue in colour and smelled like a mixture of nitrate and sulfur.

Table B: Explosive activity, continued.

Date	Index	Source	Quotation
10 June	B15	4, p. 9	...heavy overcast with p*ungent/acrid rainfall*, which caused unbearable smarting in the eyes and on bare skin upon contact and *dizziness* in the head. Some raindrops *burned holes* in the dock leaves as they fell on them and *scorched* the skin in newly sheared sheep.
10 June	B16	10, p. 14	...separate columns of fire were seen for the first time rising up above the mountains in the north; the ashy cloud rose higher and higher every day and earthquakes along with rumbling and cracking increased day by day. [Magnús Stephensen did not witness the Laki eruption and his descriptions of the eruption are based on other eyewitness accounts. The description is very similar to the one Steingrímsson gives for 8 June. It appears that the date 10 June is a mistake by Stephensen.]
11 June	B17	4, p. 9	Snowfall and snowdrift in easterly wind, that was derived from the plume.
11 June	B18	5, p. 274	...on the fourth day of the eruption I [Jón Eiríksson at Ljótarstaðir in Skaftártunga] s*aw two additional columns of fire* north of the first one and it seemed to be positioned in Skaftárjökull glacier. [The line of sight from Skaftártunga to the eruption site is such that a northeast shift appears to be toward the north.]
11 June	B19	8, p. 420	That night, right after we had put up our tent again, it started snowing and when we had slept through part of the night, ...we were woken up by three enormous cracking sounds so we saddled our horses in a hurry and rode back to the district in a snow drift and *dense ash-fall*.
11–14 June	B20	7, p. 281	As one could clearly see *three separate columns of fire and smoke* it is possible that the fire emerged from more than one source, which opened about the same time. These *columns of fire* and smoke were easily seen from the Rangárvellir district during 11, 12, 13 and 14 June. *After that came a haze* containing dust particles, which did not only spread all over the southern Iceland but also eastern, western and northern Iceland, and blocked the view.
12 June	B21	10, p. 15	A huge dark volcanic cloud emerged in the NW and dispersed a great volume of ash, scoria, sulfuric material and greyish hairy material [over the Síða district]; the land was covered by badly smelling and tormenting smoke which blocked the sunlight; the sun was seen through this dense smoke and sulfuric mist as a blood-red indistinct globe. Earthquakes and cracking sounds were frequent and the eruption site was seen through the dense cloud of smoke and mist as numerous columns of fire north of the mountains bordering the Síða district. [Stephensen contradicts his source here. Steingrímsson does not mention tephra-fall on 12 June in any of his descriptions. However, Stephensen's description is similar to that of Steingrímsson from 14 June both in style and content].
12 June–21 July	B22	3, p. 70	This absurdity and enormity continued with thunder and lightning in the air, but earthquakes and din in the earth from 12 June to 21 July. This activity was west of and within my [Steingrímsson] parish. When activity dwindled on this eldgjá [Útnorðursgjá] another [Landnorðursgjá] began to erupt east and north of us and desolated by ash-fall a whole parish, named Kálfafell [i.e., Fljótshverfi].
13 June	B23	2, p. 59	...loud claps and cracking sounds were heard from the eldgjá, the *column of steam* was so high that it was seen from Selvogsheiði in Gullbringusýsla and surrounding districts to the west, [i.e., Reykjanes peninsula, distance from Laki fissures ∼250 km.]
13 June	B24	4, p. 9	The *ash and the steam plume* was so high that it was seen all over the country, west to moors in Gullbringusýsla ...the weather was calm and clear with wind of southwest. Loud claps and cracking sounds were heard here from the northwest, along with earthquakes, also boiling and noises like commonly heard around waterfalls or as many forge hearths were blown at the same time. This noise and rumble were continuously heard from this direction for the next three weeks.
13 June	B25	2, p. 59	This same day a few men climbed the mountains bordering the Síða district to explore and locate these fires. They saw *20 columns of fire* in the so-called Úlfarsdalur Valley, which is situated north of the Síða highlands, and two of them were indescribably large and they saw 7 other columns in the hillocks north [correct is to the east] of the valley. [Total of 27 fire fountains were seen in Úlfarsdalur Valley, which is actually the numbers of openings on the two western most fissures of the Laki cone-row.]
13 June	B26	4,p 12	The activity was intense north of the mountains bordering the Síða district, with cracking and crashing sounds, fire and haze, along with earthquakes such that no one was certain whether the settlement was going to be saved. Therefore 3 farmers, who lived at the farm Mörtunga, climbed up to the highest lookout on Kaldbakur mountain to evaluate the progress of these fires in the pasture. They saw, as it appeared to them, fires in Úlfarsdalur Valley and they could recognise *22 columns of fire* emerging from the fissure.
14 June	B27	2, p. 60	...huge amount of *hairy sand* was dispersed all over [Síða], but in early evening a heavy rainfall occurred from the plume so *pestiferous and smelly* that breathing became difficult for people with respiratory problems.
14 June	B28	2, p. 60	The before mentioned *hairy sand-fall and sulfurous rain* caused such unwholesomeness in the air and the earth that the grass became yellow and pink and withered down to the roots. The animals that wandered around the fields got yellow colored and sore feet, and yellow spots were seen on the skin of newly shorn cheeps, which had died.
14 June	B29	4, p. 10	*...huge volume of ash, which contained more hairs than previous ash-fall on 9 June* [correct date is 8 June], which were bluish black and glittering, their length and thickness was similar as a hair of a seal (it has been reported that they contained iron and copper mixture); and they completely covered the ground. Where the hair fell on bare ground it was rolled up into elongated, hollow bundles by the wind. In the night that same day a heavy rain fell from the plume, despite the southeasterly breeze, which had muddy or light-blue colour and very bitter and smelly so that people with respiratory problems could hardly breathe and were dizzy. All summer birds and nesting birds fled, their eggs that were left behind were hardly edible because of their bitter and sulfurous taste.
15–17 June	B30	2, p. 60	...thunder continued to be heard from the cloud...
16 June	B31	4, p. 12	The din and the cracking, the fires and the stench along with the earthquakes to the north of the mountains bordering Síða was so frenzied, that no one was sure whether this settlement was safe.

Table B: Explosive activity, continued.

Date	Index	Source	Quotation
17 June	B32	4, p. 13	...*the column of fire rose up so high*, from the before mentioned Útnorður Úlfarsdalsgjá from where a continuous boiling sound could be heard, that sparks of fire actually advanced forward between Lambatungur, located at the west end of Kaldbakur, and Geirlandshraun, which is a elongated hill north of the Síða district, trending east-west and stretches so far west that it reaches beyond the farm Skál. *The fire column was seen [from Prestbakki farm] above the Geirlandsheiði moor*. [This description refers to the rootless eruptions in the Leiðólfsfell area (Thordarson *et al*., 1998)].
19 June	B33	4, p. 14	Southerly winds that directed the *main eruption plume northwards* towards the glaciers and frequent thunders were heard from the eruption site.
21 June	B34	2, p. 62	...*large amount of ash fell* here in the Síða district, followed by sleet and snowfall so the mountains became white. [This tephra fall occurred in strong easterly wind, suggesting origin at the Grímsvötn volcano].
21 June	B35	13, p. 593	The equinox, 21 June, was followed by rainy and foggy weather. The face of the Earth became white. Grass withered down to the roots like it had been burned. Milking cows and milch ewe lost their yield. Due to the haze and the mist the sun was blood red in colour, especially mornings and evenings. *Greyish ash or sand* was seen deposited on thin boards and white paper which was laid outside. To people it appeared to be *sulfur*, which had been dispersed over the ground, spoiled and burned the grass and was unwholesome for animals as well as humans. This *sulfuric deposit* is most likely derived from the abnormal eruption to the east of us. This deposit was mainly dispersed over Northern Iceland between the Hrútarfjarðará River and Þingeyjarfljót River [Skjálfandafljót], but not over southern and western Iceland as has been claimed by some. This could be called the grass burning summer or the sulfuric summer.
21 June	B36	4, p. 14	...Wind from the east with rain [in Síða district]...
22 June	B37	4, p. 14	...same weather continued.
23 June	B38	4, p. 17	...loud whistling was heard from Útnorðursgjá.
23–24 June	B39	4, p. 14	...same weather as before [i.e., easterly wind], which directed the plume towards the glaciers [i.e., Mýrdalsjökull and Eyjafjallajökull glacier], but the same was heard, seen and felt from the erupting fissure as on 19 June.
25 June	B40	4, p. 17	...same *easterly and south-easterly wind*, at this time the activity from the same fissure [Útnorðursgjá] was so intensive that *the flame* was seen through the cloud and so intensive that clasts and sparks were carried by the wind to Þórsmörk and Tindfjöll in the west. Because of this tephra-fall the inhabitants of Fljótshlíð and Landeyjar thought eruption had started in the vicinity, but instead turned out to be pyroclasts from here [i.e., Útnorðursgjá].
27 June	B41	2, p. 63	...*huge amount of sandy tephra* was dispersed over Síða; during the following night and day a *strong westerly wind* was blowing and blew of some of the sand [i.e., tephra] off the ground.
27 June	B42	4, p. 17	...*wind* was from *the west* and bringing with it a torrential rainfall. We here in the Síða district *saw the edge or the bottom of a huge black sandy plume* [rise from Útnorðursgjá], which *twisted and spun up over the mountains* forming bolsters. This cloud *dispersed sandy ash and pumice-like clasts* over Fljótshverfi (the eastern part of Síða), which [i.e., the pumice-like clasts] before and after did not reach this district
28 June	B43	2, p. 63	...the wind continued blowing from the west directing before mentioned plume away from us and over the Fljótshverfi district *where heavy fall of ash and pumice-like clasts occurred*. This tephra- fall stunted the grass growth this summer so it could not be cut and the whole of Fljótshverfi became desolated except Núpsstaður farm which was located furthest east.
30 June	B44	4, p. 19	...thunder and earthquakes along with loud noise from Útnorðursgjá.
30 June	B45	4, p. 24	...the steam plume was directed west towards Mýrdalur. [According to Steingrímsson this steam plume came of the lava flow in the lowlands in front of the Skaftá River gorge.]
in June	B46	5, p. 275	We have not got any exact accounts from the Síða district about what has been destroyed, but we know it has been a very difficult time for the inhabitants, because in Síða the tephra-fall has done much more damage than here [in Skaftártunga] since from the beginning of the eruption the wind has most of the time been out of the west and thus directed the cloud towards east.
6–7 July	B47	4, p. 20	...still loud noises were heard from the same fissure. [Útnorðursgjá].
9 July	B48	2, p. 64	...once again *a huge tephra-fall* was dispersed over here [i.e., Síða district], so grassing animals would not eat the grass of the fields unless the tephra was raked off, this continued for two nights, then heavy rain-fall occurred which washed off the tephra.
9 July	B49	4, p. 20	...volcanic ash was dispersed all over the Síða district, so the ground became black.
10 July	B50	4, p. 20	...*continuing tephra-fall*. ...We heard that no tephra fell in the Meðalland district.
11–12 July	B51	4, p. 20	Heavy rain and wind [in the Fire districts] so the volcanic ash was washed down in the ground or was blown off such that the ground was visible again.
18 July	B52	2, p. 65	...here all around us threats from thunder, lightning, creaking and cracking sounds went on such that a minute was not missed out for two whole days. Never had so much been going on since the gjá [Útnorðursgjá] began to erupt...more had gone on around the Skaftá River gorge and nearby areas, as was clearly visible on the ground [i.e., the soil cover] as later observations revealed; it was ripped apart and had been thrown around and had undergone amazing transformation. There [in the vicinity of the Skaftá River gorge] we found here and there fire-blobs, which had fallen down from the air and burned the grass around them as they chilled and lithified. Some of these blobs were half buried in the ground and shaped like a cow-dung. Others were shaped like twisted bundles and had pierced into the ground and broken up on impact. These fire-blobs appeared to weigh around ten pounds or more [these spatter bombs were produced by rootless eruption within the lava flow]. When these above described phenomena had been going all night and large part of the day; *a sandy and muddy ash* was dispersed over the ground here so it blackened. *This tephra-fall came from east-northeast and was different from previous ones in colour and feel*. It came from another eldgjá as later became evident. [East-northeast is the direction to Grímsvötn volcano. See text for further discussion].

Table B: Explosive activity, continued.

Date	Index	Source	Quotation
18 July	B53	4, p. 22	...*sandy ash* was dispersed all over the Fire districts such that in the Fljótshverfi district all grazing fields were destroyed as far as to the river Djúpá. [Tephra-fall from Grímsvötn volcano.]
19 July	B54	2, p. 65	...the volcanic plume stayed north of the mountains bordering the Síða and was directed towards west, occasional thunder was heard. [Continued tephra fall from Grímsvötn?]
20 July	B55	4, p. 22	...same cloudy weather with thunder, lightning, cracking sounds and earthquakes.
21 July	B56	4, p. 23	*The plume* was directed towards the northwest and *after this day* no loud rumbling sounds were heard from this Vesturgjá, despite fires continued to burn and flow from it into September.
22 July–2 August	B57	2, p. 66	...occasional heavy rainfall, and during this time *columns of fire and smoke* with intermittent thunder and rumbling were observed in the pasture.
24 July	B58	4, p. 23	...intensive *fire coloured glare* was seen in the sky...
24 July	B59	7, p. 281	*Fine-grained pumice-like material*, which resembled finely cut tobacco, has been observed to fall in many localities, for example on the Kjölur route along the Blanda River. [The section of the Kjölur route mentioned here is located in eastern part of Húnavatnssýsla in North Iceland, 250 km north-northwest of the Laki fissures. The timing of this tephra fall is uncertain but it obviously occurred before 24 July].
25 July	B60	4, p. 23	Same fire coloured glare.
28 July	B61	4, p. 23	...rain in westerly wind, with *sandy ash* and a bad smell.
29 July	B62	4, p. 25	...calm weather, for the first time rumble and a boiling sound was heard northeast of Kaldbakur mountain, on a strike with a high mountain called Blængur. The rumble and cracking was not any less than was heard earlier from Útnorðursgjá, which had dwindled considerably at this stage. Later that day *an awesome plume* emerged from the site with *ash-fall that was largely dispersed over the Fljótshverfi district and the eastern part of the Síða district*, reducing daylight such that visibility in our homes was greatly diminished. [The line of sight from Prestbakki to Blængur is the direction to the first fissure east of Laki mountain, labelled 6 on Figure 2.]
30 July	B63	4, p. 26	...thunder, rumbling and cracking sounds were heard almost continuously from all sides.
in July	B64	4, p. 25	Near the farm Skaftárdalur on the eastern side of the Skaftá River gorge lava blobs [spatter bombs], which had fallen out of the air, could still be seen, some were elongated and twisted together like a cow-dung. Some were still in one piece; others had broken up on impact. [These spatter bombs were produced by rootless eruption within the lava flow, see also description on 18 July.]
in July	B65	4, p. 25	From there [Skaftárdalur farm] *columns of fire* were seen at two locations until 14 January 1784.
1–3 Aug.	B66	4, p. 26	...same boiling continued to be heard from this gjá [Landnorðursgjá], along with earthquakes, rumbling, thunder and lightning...
6 Aug.	B67	6, p. 297	Still the entire Fljótshverfi district was completely covered with sandy ash [i.e., from the tephra fall on 29–30 July].
9 Aug.	B68	2, p. 66s	...intensive thunder and lightning was noticed around the fissure north of Fljótshverfi.
10–17 Aug.	B69	4, p. 27	...the boiling continued to be heard from Landnorðursgjá...
14 August	B70	4, p. 27	...the *plume* was directed away [from the rural settlement] by south-westerly wind.
<15 Aug.	B71	12, p. 279	*Two columns of smoke* were seen from the farm Húsafell in Borgarfjarðarsýsla, which rose above the eastern part of Kaldidalur Valley. [This description is in a letter written by Ólafur Stephensen on 15 August 1783. Here he is describing the eruption columns of the Laki eruption. From this location the columns must have been viewed over the mountains at the southern end of Langjökull glacier and to be seen from Húsafell the plume must have been at least 8.5 km high and most likely considerably higher].
17–23 Aug.	B72	4, p. 28	... the same boiling sound was heard from Landnorðursgjá and *showers, containing sandy ash*, fell frequently [in the Síða district].
23–31 Aug.	B73	4, p. 28	... activity continued as previously described, but now again intense tremor and cracking was felt from Austurgjá.
in August	B74	4, p. 27	When the smokes coalesced and the fumes in them became too heavy, a stinking and sandy rain fell out of the cloud with lightning and thunder. This occurred despite that clear and bright weather was around us.
in August	B75	4, p. 27	When the activity dwindled, which commonly was at its peak during new and/or full moon, the fields recovered to some degree.
1–7 Sept.	B76	4, p. 28	Rain and acrid rain, fog and mist, thunder and lightning occurred frequently that week [in the Fire districts].
7 Sept.	B77	7, p. 281	...in the morning of 7 September *fine-grained ash* fell on a boat west of Vestmannaeyjar, so the sail and cloth covers became dark grey in colour in 2–3 hours.
14 Sept.	B78	4, p. 29	...*heavy ash-fall in easterly wind*, which only reached as far west as Geirlandsá. [Geirlandsá River originates in Laufellsmýrar up in the Síða highlands flowing almost directly south to the central part of the Síða district. Thus it is impossible that this ash-fall came from the Laki fissures because the wind was blowing from the east at the time. The only possible eruption site which could have produced this ash and caused this type of dispersal is Grímsvötn.]
14–26 Sept.	B79	4, p. 29	...at nights the glare from the eruptive fissure reached up to the middle of the sky, especially in two places as it was seen from Prestbakki. From Vesturgjá the glare was seen between Lambatungur and Kaldbakur mountain, but from Austurgjá between Kaldbakur and Vothamrar.
26 Sept.	B80	4, p. 29	*An additional column of fire and steam*, which had been seen few times before, appeared far east- northeast from Síða, due north of Lómagnúpur, but northwest from Öræfi. This activity was ongoing until 24 October. That day intensive earthquakes and strong sulfuric stench was noted from east-northeast, which indicated that this event was not all over yet as became evident later... [These directions leave no doubt that Austur-Landnorðursgjá is Grímsvötn volcano].
25 Oct.	B81	4, p. 30	...*a high column of fire* ascended into the air from there [Grímsvötn] and was followed by an intensive lava surge [from Útnorðursgjá] along with rumbling and claps for the next five days.
24 Nov.	B82	4, p. 31	The activity was still so intensive in east-northeast, that the *column of fire* were seen above mountain Kaldbakur. *In early December* the activity started to dwindle and the glare, which had been seen almost daily above the three gjá's or vent areas, diminished.

Table B: Explosive activity, continued.

Date	Index	Source	Quotation
in 1783	B83	13, p. 593	The spring 1783 was reasonably good, but with occasional frost. More common was sunshine and clear weather until Trinitatis [15 June]. Thereafter a mist, haze and fog were seen in the air everywhere, so the sun was hardly seen even in clear weather. Right after equinox, 21 June, rainfall along with fog came over. Then the face of the earth became white. The grass withered down to the roots, like it had been burned. Milking cows and sheep lost all milk. The sun appeared blood red, especially in the mornings and evenings, due to the mist or the haze. Gray sand had deposited on a few thin boards that had been lying outside and on spread out paper. It appeared to most people that it was sulfur, which was spread over the ground and damaged the grass and had unwholesome effects on animals and humans. Surely this sulfur might be from this ongoing and abnormal eruption east of us. The sulfuric deposit was mainly dispersed over the area between the rivers Hrútarfjarðará and Þingeyjarfljót [Skjálfandafljót], but not over southern and western Iceland as has been previously said by some. This summer could be called the summer of the Grass-burns or the Sulphuric summer. ...The mist and the haze, and even acrid rainfall, was observed here off and on well into the fall, but the stench people could smell well into the winter. Brigs and small fishing vessels came to Iceland this summer. Some of them went astray because of the haze and the smoky mist that spread all over.
in 1783	B84	14, p. 456	Because of this eruption sand and ash were dispersed all over the island. The ash-fall, the haze and the mist was so intensive that the normal visual field [i.e., view between farms] was reduced considerably and the sun was seen blood red in color. This was most effective shortly after the mist was first observed or around Trinitatis. It has been verified that this volcanic dust fell in Bergen [Norway] though without any damage to vegetation or livestock.
January 1784	B85	4, p. 32	Bad smell and odour was often noticed throughout the year [1784], when the wind was blowing from the direction of the crater area. Fire was still seen Austur-Landnorðursgjá. From Kirkjubæjarklaustur it was seen just north of Þverárfjall mountain. It was more clearly seen from the Öræfi district, due to its location. [These directions give Grímsvötn as the eruption site.]
8 April 1784	B86	4, p. 34	This jökulhlaup, observed in the river Súla on 8 April, which was Maundy Thursday, ... the putrid smell and the stench which followed was so strong, that it could be sensed in every nook and corner inside the farms and never before has anything like it been reported here. A flash flood was observed in the river Skeiðará at similar time. Jökulhlaup's recurred occasionally until the Midsummer Eve. *...The easternmost column now became very black*, but since most of this time the wind was blowing off the sea [southerly winds] the tephra fell mostly on the mountainous desert in the north. Twice, a small amount of ash fell from the cloud here in Síða.
Summer 1784	B87	10, p. 31	The moor, were many farms in the Síða district had their summer dairy farms due to good pasture lands for the grassing livestock, *was now scorched or completely covered by volcanic sand and ash*. As we travelled, further north into the pastures *the thicker the tephra cover became, reaching 4–6 inches in thickness*. Some compaction of the deposit had occurred from the year before and at few places some plants and straws were seen to sticking through the tephra cover. The *once grassy Síða highlands was now completely covered with still thicker tephra sheet* and no plants were observed at all.
January 1785	B88	4, p. 43	The year 1785 started with severe frost, such a piercing and profuse cold caused by the fiery fumes commonly seen as a bluish mist in the air on clear days.
Spring 1785	B89	4, p. 43	The spring was moderate, but in the spring loud rumbles were heard from the volcanic plume [i.e., Austur-Landnorðursgjá], most intensively on the 4 and 26 May, shortly after a jökulhlaup in the Núpsvötn River. [This was the last time fires were noticed at Grímsvötn.]
Summer 1794	B90	11, p. 558	Pálsson's observations at Lauffellsmýrar bogs: Prior to the eruption this area was impassable bogs/mires, but during the eruption they were filled up by black scoria so now it could be passed on horses without any trouble at all. The scoria had completely disappeared into the grassroots, so the area has gained back its boggy appearance and with time it will become the same impassable bogs as it was before.
Summer 1794	B91	11, p. 560	Pálsson's observations on the tephra cover at Galti mountain: As I passed over, I measured the thickness of the scoria cover which was still preserved in the slopes next to the lava flow, eleven years after the eruption. It was usually around 6 inches thick, even on a slope where one expects that large portion would have been removed by wind and melt water action during this long interval [that has passed since the eruption came to an end].
Summer 1794	B92	11, p. 567	Pálsson's observation during his hike across the lava to the Laki cone-row: We were now at the place where I [Sveinn Pálsson] had decided to walk across the lava flow [to the craters] and the lava was about quarter of a mile wide [1/4 Danish mile = 1884 m]. Finally we came across a deep and wide channel with a smooth bottom, which the lava had flowed down during the final stage of the eruption and cooled down without breaking up. We managed to cross the channel and the western branch of the lava flow without any mishaps and reached the before mentioned smoky hillocks. ...After a brief rest, we climbed the closest knoll, which appeared to be the highest one. ...I was very surprised when I reached the top and saw that the knoll was hollow inside, similar to an Icelandic fold or ruins were the walls are the only thing left standing. The floor of the knoll was at similar level as the base of its slopes. It was made of solidified lava, but the walls on the inside looked like they had been built up of incinerated lava blobs and the brink was very thin with lot of concentric cracks. ...In one of those lava made fences was an opening, at the same level as the floor and made up of same material, which led to a narrow channel extending towards the large channel mentioned above. This knoll contained two such craters or bowls, where one had opened a channel towards SW and the other towards NE. The diameter of these bowls was about 30 fathoms at the top and 10 at the base. ...I investigated some other knolls at this location and they were all similar to the one already described. On the outside they were mainly built up of reddish gravel-size scoria, on the inside however they were made up of solidified lava and from each of them a channel extended out into the main lava field. [The craters described here are located on fissure 3 (Figure 3)].

Table C: Lava flows

Date	Index	Source	Quotation
in June	C1	3, p. 69	This lava flow [*the Laki lava flow*] comes from one of *the boggiest dells* here in the Síða highlands, to the north of us.
in June	C2	1, p. 273	The northwestern sector of the highlands, which used to be grassy fields, is now *covered by lava*. Not only did we loose a good sheep walk, but also the fields where angelica roots and Iceland-moss were be picked for food and are of vital importance for the inhabitants.
9 June	C3	4, p. 9	The Skaftá River, which ran eastward at the foot of the Síða scarp, ...began to *dwindle* considerably.
10 June	C4	4, p. 9	The channel of the Skaftá River *dried up* completely, apart from the local tributaries that flowed into it.
10 June	C5	10, p. 14	...To everybody's surprise the Skaftá River *dried up* and disappeared on this day.
11 June	C6	2, p. 59	...it was noticed that Skaftá River had *dwindled considerably* apart from the tributaries, which flowed into it from the mountains bordering the Síða district.
11 June	C7	8, p. 420	...on the third day after Whitsunday three of us from the farm Skál went woodcutting up in the mountains. Then we noticed that the great Skaftá River had dried up, therefore we cut the trees into the gorge. North of us further up the gorge we saw a huge smoke or steam cloud. Late that day we went to explore this further and then we noticed, just a short distance from we were, that *the whole gorge was filled with lava* and its sides were like glowing iron. The rocks, both the glowing and unburned ones collided in the air causing loud cracking sounds.
12 June	C8	2, p. 59	...*the lava surge first emerged* out from the Skaftá River gorge with incredibly loud cracks, claps, din and rumble. *The discharge of the lava was similar to that the Skaftá River*, which is one of the larger rivers in Iceland and was at a high stand at this time. When the lava poured into the rivers or quicksand, which happened to be in its way, loud claps and rattles were heard. To begin with the flow advanced at torrential speed along the main river channel, then it poured over the older lava flows which were in its path and destroyed most of the fields and pastures belonging to the farm Á. [This was the first of five lava surges to emerge from the Skaftá River gorge].
12 June	C9	3, p. 69	...out from the gorge, named Skaftárgljúfur [Skaftá River gorge], emerged such *a large flood of lava*, with the colour of molten copper in a crucible, that it was similar to the water level in the Blanda River during high stand as it is seen at your place or in the vicinity of the farm Bólstaðarhlíð.
12 June	C10	4, p. 9	...*a lava surge* emerged out of the Skaftá River gorge with enormous effluent, cracking, din and rumble. When the lava fell into quicksand, fresh water springs, or river channels loud claps were heard, just like many cannons were fired off at the same time.
14 June	C11	2, p. 60	The following night *the flow of lava out the Skaftá River gorge* and along the mountain Árfjall was so intensive that the ground trembled and vibrated from incessant strokes of lightning and thunder, so almost no one got any rest or sleep that night. At that time the lava burned up and destroyed all land between Skálarstapi and Nesrof [Nes], along with Brandaland, which belonged to Kirkjubæjarklaustur. This day the flow reached *Holtsgarðar* where its *advance was halted* for awhile. [This is the second lava surge that emerged from the Skaftá River gorge].
14 June	C12	4, p. 11	...a*an awful lava* surge emerged from the Skaftá River gorge, such that the whole gorge appeared to be *filled* with lava to the brim. This surge completely abolished and destroyed the following farms which belonged to the abbey and the king. Á in Síða and Nes in Skaftártunga, each worth 12 hundred coins of silver. It also completely covered the old lava flows between the Síða and Skaftártunga districts, which were largely grown up with brushwood and trees, very useful pasturelands. This area included Brandaland, a good woodcutting area, belonging to Kirkjubæjarklaustur ...Brandaland was located westsouthwest of Skálarstapi in the nook where the river turns east along the Síða scarp and bordered by a branch from the Skaftá River. This surge destroyed the so-called Skálargarðar and Holtsgarðar, where it became stationary for awhile. Another branch of lava advanced south towards Meðalland, where it flowed first over the Botnar and Steinsmýri lavas. [This description is under 16 June in the original source, which appears to be a mistake. See text for further discussion].
14 June	C13	8, p. 420	The night before Trinitatis [15 June] the *flow of lava* was so intense that no one had experienced such enormity and people thought that this would be their last day alive. At this time the lava flow was 20 fathoms away from the graveyard at the farm Skál and it was as high as highest sea-cliffs (i.e., Vogastapi) [Vogastapi is at the Reykjanes peninsula. The cliffs that face the ocean are ∼40m high].
15–17 June	C14	2, p. 60	...during these days *the lava flowed at the same rate* towards south and southwest from the farm Skál, which was still standing, the flow crept into the older hollow lavas, caused them to swell up so high that the ones which didn't observe it would find it hard to believe. These old crags and boulders were thrown up into the air with a cracking noises as many cannons were fired off, but on impact a loud claps and rumble were heard. [here the Laki lava is advancing over the 934AD Eldgjá lava].
17 June	C15	4, p. 13	...the column of fire rose up so high, ...that sparks of fire actually advanced forward between Lambatungur, located at the west end of Kaldbakur, and Geirlandshraun, which is an elongated hill north of the Síða district, trending east-west and stretches so far west that it reaches beyond the farm Skál. *The fire column* was seen from Prestbakki farm above the Geirlandsheiði moor. [This descriptions refers to the rootless eruptions in the Leiðólfsfell area (Thordarson *et al.*, 1998)]
18 June	C16	2, p. 61	...*an enormous lava surge* emerged from Útnorðursgjá, filled the Skaftá River gorge up to its brims and advanced rapidly out over the fluvial plain so it looked like it was on fire from one mountain side to another. ...the lava *flowed so rapidly* out from the gorge, that it resembled the discharge in the river Hvítá during high stand at Skálholtshamar and the *flow velocity* was similar to that in a river during the period of spring-thaw... [The third lava surge to emerge from the Skaftá River gorge; Skálholtshamar is a cliff at the bank of the river Hvítá near the old episcopal seat Skálholt].
18 June	C17	4, p. 13	...again *a lava surge* emerged from the Útnorðursgjá, so the Skaftá River gorge, which was both wide and deep, was filled with lava to the brim.
19 June	C18	4, p. 14	*The lava that rushed forward* this day, filled the channel of river Skaftá and in 5 days it wasted and destroyed the farm Hólmar, both farms at Fljótar, Hólmasel and Botnar.

Table C: Lava flows, continued.

Date	Index	Source	Quotation
19 June	C19	2, p. 62	...the flow split up, *one branch* advanced eastward along the mountain [Skálarheiði], but another due south along the channel of the river Melakvísl. ...part of this lava was so high that it was equal the height of Múli next to the farm Skál or *about 60 fathoms* high. In forcing its way along the slopes the flow pushed itself under the soil cover and bundled it up like a cloth. [One fathom is equal to 1.67 m; 60 fathoms = 100 m].
20 June	C20	2, p. 62	...*the lava* continued to advance as before and flowed eastwards burning low lying grounds in front of the farm Skál and all the way east to Krókstorfa. ...The branch which advanced down the riverbed of Melakvísl continued flowing due south. ...This day a *few farmers went to explore* what the eruption was doing north in the pasture area. *Lava* had advanced eastwards towards the *middle of the pasture* and destroyed good quality grass fields. *Little more than two thirds* of the pasture area was lost under lava along with swan-hunting and bird-nesting grounds (which provided the inhabitants with eggs), fields where Iceland-moss and roots from angelica were picked, which was part of the inhabitants' diet.
20 June	C21	6, p. 296	...an *exploratory party* went as far north into the highlands as possible to investigate the status there. Those who knew the highlands recognised that the fires emerged from three small lava streams in the northern part of the pasture (almost "dagleið" to the west from the glaciers), located on a flat fluvial plain north of the Hellisá River. The valley [Varmárdalur] where the inhabitants of Síða picked roots was east of the lava streams. Activity increased with loud cracking, ejecta, ashy cloud, yes a storm emerging from the earth. *The lava streams* grew steadily and covered more ground as they moved away from the source until they merged into one main stream, which flowed like molten copper, first into above mentioned valley and when it was filled, the lava threw itself westwards off the mountains above the southwestern part of the Síða district, into the Skaftá River gorge. ["Dagleið" was a day's journey on a horse, ∼25 km].
21 June	C22	2, p. 62	This Saturday when the lava passed over the Melakvísl rapids, it *ran very rapidly* across the Steinsmýrarfljót River and onto the Stekkjatún grass fields north of the farm Hólmasel.
22–23 June	C23	2, p. 63	...this day and the following day *the lava advanced eastwards* down the river bed of the river Steinsmýrarfljót and stopped just west of the farm Efri-Steinsmýri.
23–26 June	C24	2, p. 63	...the *lava flowed steadily* out from the Skaftá River gorge and earthquakes were felt in between, intensive thunder and lightning occurred all around us.
24 June	C25	4, p. 17	...men from Skaftártunga district went to explore what was happening to the north of the settlement;. they saw that the lava had emerged from the channel of Hellisá River, here in the pasture.
29 June	C26	4, p. 18	Now, for the third time, *an enormous lava surge* came from above us [i.e., from north], so the area between Skaftártunga district and Árfjall mountain was once again like one continuous fire. [This is the fourth lava surge from the Skaftár River gorge].
29 June–12 July	C27	2, p. 64	...the *flow of lava did not dwindle* a bit, either day or night. However, the flow was pulsating, sometimes more and sometimes less.
13 July	C28	2, p. 64	...*the lava swelled up and flowed east* towards Dælur and Fjarðará River, blocked the river in its gorge, then followed its channel advancing beyond the promontory. Then part of the lava flowed onto the Dalbær moorlands and covered them with lava, but bulk of the lava rushed into the gorge and then over the high waterfall Stapafoss, filling the large and deep gorge with lava to the brim, which continued for four days. At that time the gorge could not contain the lava, which then advanced over the grass fields of the monasterial farm Dalbær and then up to the farmhouse, which it smouldered to ashes and then buried it by thick lava.
14 July	C29	4, p. 21	...the same day as the lava advanced over the waterfall [i.e., Stapafoss], *the fourth and the last lava surge emerged from Skaftá River gorge*, with intensive boiling, cracking and clapping, and enormous din, like everything was going berserk. [This is the fifth lava surge from the Skaftá River gorge].
18 July	C30	4, p. 22	The activity was most intense on 18 July and I [Steingrímsson] couldn't help thinking that all hell was breaking loose.
18 July	C31	2, p. 65	...here all around us, such threats from thunder, lightning; creaking and cracking sounds went on that not a minute was missed out for two whole days. Never had so much gone on since the gjá [Útnorðursgjá] started to erupt.
21 July	C32	4, p. 23	...*after this day* no loud rumbling sounds were heard from this Vesturgjá, despite those fires were seen and lava continued to flow from it into September.
29 July	C33	4, p. 26	...this day rumble and boiling sound was first heard northeast of mountain Kaldbakur, in the strike of a high mountain called Blængur. [Onset of activity on fissure 6 to the northeast of Laki Mountain].
30 July	C34	4, p. 26	...thunder, rumbles and cracking sounds were heard almost continuously from all sides.
31 July	C35	4, p. 26	...*a steam cloud* was seen advancing down the Hverfisfljót River gorge. [In the earlier Eldrit Steingrímsson says this to have happened on 3 August. See also Thordarson this issue].
in July	C36	4, p. 25	...all that month along with August and September *the lava continued to flow* out of the Skaftá River gorge, but in late September *the flow dwindled and stopped*. At this time sheep and other goods were taken over the lava flow west of Skaftárdalur, because the lava that was still flowing further up in the pasture area kept the rivers to the north of the Skaftárdalur farm dry.
3 August	C37	2, p. 66	...people noticed that *the water in Hverfisfljót River was getting warmer*. The temperature increased steadily, until it finally dried up.
3–4 August	C38	4, p. 26	...along with *flowing lava* to the north of the mountains, which *dried up Hverfisfljót River*.
7 August	C39	4, p. 26	...*the first lava surge* emerged from the Hverfisfljót River gorge. On 8 and 9 August it advanced down the one of channels of the river Hverfisfljót, the one which was closest to the eastern margin of Síða district towards the south-southwest. The lava flowed far out onto the sandur plain, beyond the hill Orustuhóll. ...on the eastern side [of the gorge] it advanced a short distance beyond Dalshöfði. [This was the first lava surge from Landnorðursgjá that emerged from the Hverfisfljót River gorge. The lava flow front was between Kaldbakur and Dalshöfði mountains on 7 August but on 9 August it had advanced beyond Þverárfjall mountain].

Table C: Lava flows, continued.

Date	Index	Source	Quotation
9 August	C40	2, p. 67	...that day *a lava surge* emerged from Hverfisfljót River gorge and advanced like running water out onto the sandur plain, one mile [i.e., Danish mile = 7532 m] beyond the so called Orustuhóll Hillock and from there due south until it stopped. [The correct distance which the lava advanced beyond Orustuhóll is 4 km].
10–17 Aug.	C41	4, p. 27	...*intensive flow of lava* out of the gorge, so it was feared that it might advance over the Fljótshverfi district.
17-23 Aug.	C42	4, p. 28	...the flow of lava had dwindled considerably [from Hverfisfljót River gorge].
1 Sept.	C43	4, p. 28	...the second lava surge emerged out of Austurgjá. [As is evident from the quotation above this was the second lava surge to emerge from the Hverfisfljót River gorge].
1-7 Sept.	C44	4, p. 29	...the lava flow was so vigorous north of the mountains [bordering the Síða district] that it dried up and consumed all rivers which used to flow out on the sandur plain.
10–11 Sept.	C45	4, p. 29	...yet another lava surge emerged out of the same gjá and advanced between the previously formed lava streams. [This is the third lava surge to emerge from the Hverfisfljót River gorge].
14–26 Sept.	C46	4, p. 29	...a great break in flow of lava out from both gorges ...because both Skaftá and Hverfisfljót rivers along with all local tributaries have reappeared and not caused any considerable damage.
26 Sept.	C47	4, p. 29	...was followed by increasing activity and *lava production* north of the mountains [bordering the Síða district] and again dried up all the rivers which had reappeared earlier, so people could walk unhindered across the lava for example next to the farm Skaftárdalur as mentioned above. [This lava surge dried up the Skaftá and Hverfisfljót rivers again. This increase in the activity is most likely related to the formation of one of the fissures at Fljótsoddi, because it is between to the glacial outlets of both rivers, which are separated by less than 2 km. This is the fourth lava surge to emerge from the Hverfisfljót River gorge].
25 October	C48	4, p. 30	...a high column of fire ascended into the air from there [i.e., Grímsvötn], which was followed by a aweful *lava surge* [from Landnorðursgjá] along with rumble and claps for the next five days. This was the *last lava surge* that emerged from Hverfisfljót gorge and it was also the most fearful and intensive surge, which the Lord God directed between the earlier ones.
November	C49	4, p. 31	All November *small lava pulses* flowed onto the eastern lava branch, so rumbles were heard.
in 1784	C50	4, p. 32	Neither I or other trustworthy inhabitants observed any lava flowing out of the two gjá's, which had produced the bulk part of the lava flow, *after 7 February* or when 15 weeks had passed of the winter. This eruption lasted therefore for *8 months*.

Table D: Sense of directions in the Fire Districts

Date	Index	Source	Quotation
8 June	D1	1, p. 272	After a period of intensive earthquakes eldgjá started to erupt, on 8 June, in so called Síða highlands due *southwest* of Úlfarsdalur glacier. [This indicates that southwest was sensed from N215° to 225°E].
8 June	D2	5, p. 274	On Whitsunday I first saw a fire column and smoke *northeast* from my home [Ljótarstaðir in Skaftártunga], but north of Síða, which were thought to be located within the glacier where Grímsvötn are situated. [The direction from Ljótarstaðir to the craters at Hnúta is N24°E, i.e., northeast = N24°E].
8 June	D3	6, p. 296	Three columns of fire were seen from the central part of Síða or *north of the Mörtunga valley* as it was seen from the farm Prestbakki ...[A line from Prestbakki to Mörtunga is the direction towards the southwestern most craters of the Laki cone-row. Consequently the direction for northwest is actually N320°E as sensed in the Síða district at the time of the eruption].
9 June	D4	4, p. 9	But the Skaftá River flowed to east along the Síða escarpment. [This is one of many descriptions where Steingrímsson says that east was parallel to the scarp. Therefore east = N65°to 75°E].
12 June	D5	4, p. 9	To begin with the lava advanced along the main channel of river [Skaftá], flowed out over the older lavas [Eldgjá lava, 934 AD], which were on either side of the river extending from the gorge *east* towards Stapafoss. [The Skaftá River ran eastward along the scarp and Stapafoss was a waterfall in the river next to the hillock Systrastapi. The line of view from the lava fields towards Systrastapi is parallel to the scarp. East = N65° to 75°E].
16 June	D6	4, p. 11	It, [i.e., farm Brandaland] was located *west-southwest* of the Skálarstapi. Hillock... [This gives west-southwest = N245° to 255°E].
17 June	D7	4, p. 13	...the column of fire rose up so high, from the before mentioned Útnorður Úlfarsdalsgjá [the northwest fissure located in Úlfarsdalur Valley] from where a continuous boiling sound could be heard, that it actually advanced forward between Lambatungur, located at the west end of Kaldbakur, and Geirlandshraun, which is a elongated hill north of the Síða district, trending east-west and stretches so far west that it reaches beyond the farm Skál. The fire column was seen from Prestbakki farm above the Geirlandsheiði moor. [Here the orientation of Geirlandshraun is said to be east-west, but is actually N70°E].
19 June	D8	4, p. 14	At this time the main lava stream advanced with flying cinders *southeast* towards Meðalland, mostly it flowed down the channel of River Melakvísl which before connected Skaftá River and Botnafljót River. [This gives southeast = N150°E].
24 June	D9	4, p. 15	On before mentioned 24 June, the new lava had built up a high pile, I was standing up on a cliff just north of the farm Efri-Steinsmýri, looking *west* over the lava flow and could only see the top of Mt. Hafursey. [This gives west = N265°E].

Table D: Sense of directions in the Fire Districts, continued.

Date	Index	Source	Quotation
27 June	D10	4, p. 17	...wind was from the west and carried with it heavy rainfall. We here in the Síða district saw a huge black sandy cloud rise from Vesturgjá, which twisted and spun up over the mountains forming bolsters. This cloud dispersed sandy ash containing some pumice-like lapilli scoria over Fljótshverfi and the eastern part of Síða. This was by far the most voluminous tephra-fall to be dispersed over these districts. [This tephra fall is derived from the tuff cone to west of Laki mountain. Thus, with reference to the dispersal direction of the tephra fall, west = N280° to 300°E].
13 July	D11	4, p. 21	...the flow advanced from the west along the channel of river Skaftá into the narrows above Stapafoss waterfall ...from there the river continued in a deep channel *east-northeast* along the Klausturfjall mountain. [This gives eeast-northeast = N25° to 35°E].
29 July	D12	4, p. 26	...this day rumble and boiling sound was first heard northeast of Mt. Kaldbakur, *in the strike of a high mountain called Blængur*. [This gives northeast = N350°E].
9 August	D13	2, p. 67	...that day a lava surge emerged out from Hverfisfljót gorge and advanced like running water out onto the sandur plain, one mile [i.e., Danish mile = 7532 m] beyond so called Orustuhóll Hillock and from there due south until it stopped. [This gives south = N180°E].
14 Aug.	D14	4, p. 28	The lava was rumbling *northeast* of Eiríksfell. [This gives northeast = N350° to 360°E].
26 Sept.	D15	4, p. 29	An additional column of fire and steam, which had been seen few times before [i.e., 18 July] far *east-northeast* from Síða, due *north* of Lómagnúpur, but *north-northwest* from Öræfi district.
January 1784	D16	4, p. 32	Fire was still seen at the Austur-Landnorðursgjá. *From Kirkjubæjarklaustur it was seen just north of the Mt. Þverárfjall*. It was more clearly seen from Öræfi district, due to its location. [The line Kirkjubæjarklaustur to Mt. Þverárfjall gives east-northeast = N20° to 30°E].